⑫ **LEVEL** II

RADC-TR-78-211
Final Technical Report
October 1978

SCANNING CURSOR DEVICE

G. W. Hunka
L. C. Conant, Jr.

RCA/Government and Commercial Systems

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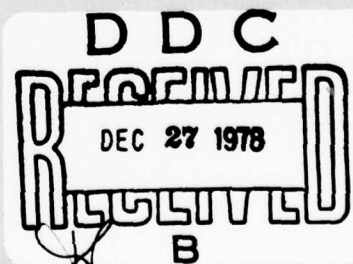
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Air Force Systems Command
Griffiss Air Force Base, New York 13441

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Digitizing	Photosensitive Linear Array

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A developmental model of an aided-track digitizing cursor used in conjunction with a digitizing table is described; this cursor can significantly increase the efficiency of digitizing graphic materials. The cursor incorporates a rotatable linear photodiode array onto which the feature being digitized is imaged. Processing of the array output produces a count indication of the deviation of the feature from the table encoder fiducial marking. A dedicated minicomputer is used to combine the digitizing encoder outputs with the array correctional counts to derive accurate coordinate values

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in the presence of tracking errors up to 1/16th inch. Rotational commands are generated by the computer to orient the array perpendicular to the traced feature for maintaining accuracy in cases where curvatures exist in the traced function. Rotation through ± 360 degrees permits closed contours to be traced with no sacrifice in encoding accuracy. Preliminary tests have shown correctional accuracies of better than ± 4 mils can be achieved with the system, equaling the resolution accuracy of the digitizing table.

Algorithms and software developed for this device allow compatible operation with the Lineal Input System (LIS) used in generating cartographic materials. The LIS System was developed by the Experimental Cartographic Facility, RADC, Griffiss Air Force Base, NY.

PREFACE

The work reported in this Technical Report was performed under RADC Contract F30602-76-C-0443 entitled, Scanning Cursor Device, by the RCA Advanced Technology Laboratories (ATL), Camden, New Jersey.

The following RCA personnel contributed to this program: G. W. Hunka, L. C. Conant, Jr., B. W. Siryj, and C. L. Saxe. Mr. J. J. Rudnick acted as Project Leader.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

EVALUATION

This report includes an area supporting an integrated program designed to introduce automation into the cartographic processes.

It directly addresses the needs of TPO thrust R2D to develop an increased capability of converting analog cartographic source material into a digital record.

The Scanning Cursor Device, operating in the transmissive mode, simplifies a tedious and error prone digitizing procedure. It allows an operator to make small digitizing errors which are automatically computer corrected. Results are an increased overall conversion rate while maintaining required accuracy.

Stanley P. Damon

STANLEY P. DAMON
Project Engineer

Section I

INTRODUCTION

A. COORDINATE DIGITIZING TABLES AND SYSTEMS

Digitizing tables are a common means for converting graphic material into digitized x-y coordinate data points which can be stored, edited, and used for recreating the original or modified functions.

A coordinate digitizing table consists generally of a movable, handheld cursor containing a fiducial mark, such as a crosshair, used for tracking desired graphic material placed on an encoding table. The table provides a means for sensing the coordinate position of the cursor with respect to a table coordinate axis as the cursor moves on the table top. Both opaque and backlighted tables are available for use, and can range in size from 12-inch x 12-inch tablets for computer graphics to 72 x 72 inches for high precision digitizing of artwork.

The aided-track cursor to be described was developed for use on a backlighted digitizing table such as manufactured by Instronics Ltd. of Stittsville, Ontario, Canada and known by the trade name Gradicon. In this table, cursor position sensing is remotely achieved by having an x-y motor-driven carriage servo-slaved to cursor motion by magnetic position sensing. Coordinate data is generated by incremental optical encoders coupled to the carriage guide system capable of motion over a 42 x 60 inch area. The carriage also contains a light source for backlighting the graphic manuscript; this source follows the cursor as the carriage motion tracks cursor position. Motion of the cursor is measured in counts per inch. It should be pointed out that use of the aided-track cursor is not necessarily restricted to this table but is applicable to any backlighted system.

The digitizing table is the basic source of cartographic data used in generating the variety of manuscript materials in circulation. It is the starting terminal of an extensive overall data handling system specifically designed for mapping operations. The aided-track cursor equipment must perform compatibly with the digitizing station program known as the Lineal Input System (LIS). LIS is an automated online computerized system using off-the-shelf general purpose minicomputers, graphic display devices, peripheral disk pack and tape drives, printers, plotters and lineal digitizers complemented by both vendor supplied and custom developed software. The LIS is a major tool both for initially creating an error-free digital cartographic data base of lineal features and for maintaining the data bank thereafter with selective updating of feature data. The production prototype system is incorporated into the production environment of the Advanced Cartographic System (ACS) of the Defense Mapping Agency (DMA) Centers.

1

B. AIDED-TRACK CURSOR DIGITIZING

As an outcome of feasibility studies,[1] an aided-track cursor was constructed which can result in a significant increase in tracing speeds while relieving the operator fatigue common to the manual function tracking operation. The feasibility model, while adequately establishing the concept, was not a practical device, particularly with respect to size. The overall size is directly related to the optical path length; and this in turn, is a function of the viewing area chosen. By decreasing the viewing port diameter from 2 inches to 1 inch, the optical path was halved, resulting in a smaller, more compact aided-track cursor as developed under the present program, having overall dimensions of 3-1/4 inches wide x 5-1/4 inches long x 1-3/4 inches high.

In the intervening time between these programs, a significant improvement in remote operation of the linear photodiode array used in the aided-track concept was achieved by the array manufacturer (Reticon, Inc.). Placing the phase drivers of the array on the array chip minimizes line unbalances, allowing remote operation over several feet without serious degradation of the array output. This new array, the RL64P, was incorporated into the design of the developmental cursor described in this report. Development of the cursor was under the sponsorship of the Experimental Cartographic Facility at the Rome Air Development Center. The cursor design goal was to tolerate tracking errors of up to ± 0.053 inch, correcting the error to within ± 4 mils of the true coordinate value at maximum tracing velocity. The reticle for this tracking cursor is shown in Figure 1. Coordinate values from the table encoders are referenced to the center fiducial dot shown within the aided-track circles. These values are outputted at 40-micrometer (1.6 mil) increments of x or y motion of the cursor. The center dot represents the extrapolated intersection of the crosshairs of the reticle. Any feature within the aided-track circles will generate the necessary correction factors with respect to the encoder values. The inner circle with a diameter of 0.062 inch is used to trace features in denser areas, while the greater-diameter (0.106 inch) circle is used for relatively well-separated features, where increased tracing speeds are possible.

The key feature of the aided-track cursor is the linear photosensitive array consisting of 64 photodiodes spaced at a pitch distance of 2 mils. The array is self-scanned repetitively at 25 kilosamples per second, at an output rate of approximately 362 scans per second. While the operator views the function to be digitized (which can vary in line width from 4 to 20 mils), it is simultaneously imaged onto the array

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[1] Scanning Cursor Techniques, RADC-TR-76-363, Final Contract Report, prepared by RCA Advanced Technology Laboratories, December 1976. (A034599)

2

Aided Track Circles
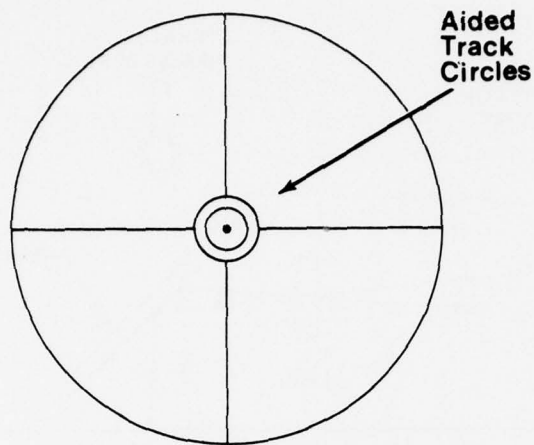
Figure 1. Aided-track reticle. Cursor fiducial markings showing the aided-track circle. In operation feature being tracked must be maintained within aided-track circle to generate coordinate-correction factors. Two circles permit operation in a fine or coarse mode.

by means of an optical beamsplitter and a 0.75-inch (19-mm) focal length lens working at 1:1 magnification. *

The variation in position of the feature being tracked with respect to an initial reference element is detected, then converted to a digital count, and scaled by the array pitch distance. The distance then serves as a correction term for the x-y coordinate values obtained from the table encoders.

For achieving accuracy in the presence of line curvature, the array position is maintained orthogonal to the curve being traced. A computer used in conjunction with the cursor calculates the desired array position from prior coordinate values, and provides a control command. Rotation of the array mounting platform is servo-controlled by means of a miniature motor-potentiometer assembly housed within the cursor.

Because of the small dimensions involved, small angular inaccuracies (in the order of 5 to 10 degrees) can be tolerated, and will have only second-order effects on the overall encoding accuracy. By allowing rotation through angles greater than ±360 degrees, closed contours can be uniquely traced without degradation in accuracy.

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* (This concept employing photosensitive arrays was designed for use on backlighted tables, such as shown in Figure 2. The application to opaque-top digitizers, using reflective techniques, is presently under investigation, under contract F30602-77-C-0243.)

3
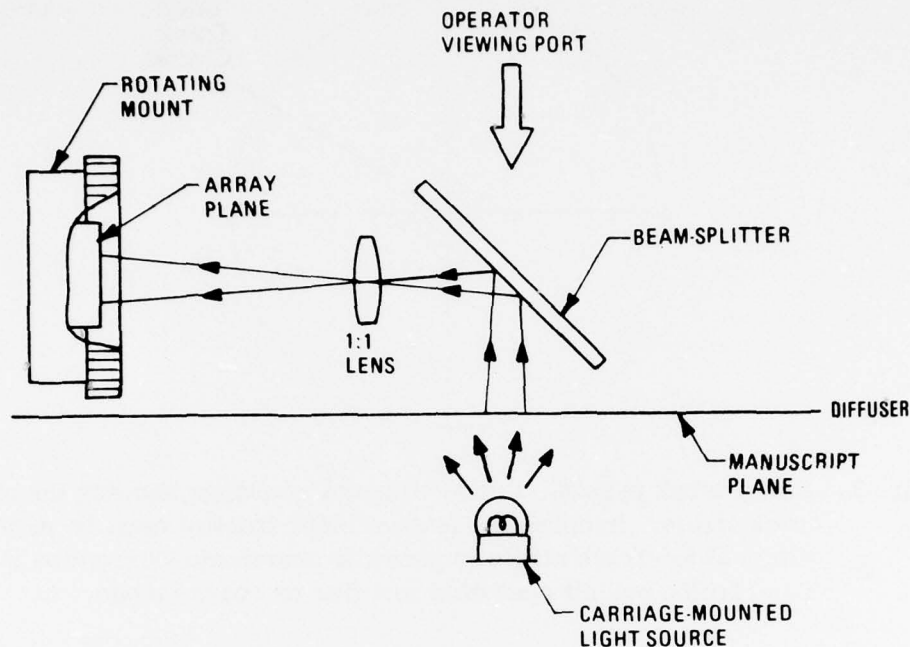
Figure 2.   Configuration of a backlighted scanning array cursor.

Figure 3 illustrates the concept of array rotation in following curvatures to preserve the machine accuracy. Distances shown in the illustration for the various sample points are exaggerated for clarity. In actual operation, the array is sequentially scanned at a high rate, so that only small angular changes are required from point to point.

Some key parameters of the aided-track system discussed above are given in Table 1 following, summarizing performance and operational features of the system.

C. GEOMETRY OF THE AIDED-TRACK CONCEPT

In the ideal case, the array would rotate about a center element onto which the center dot of the cursor reticle is imaged. Since encoder output values are referenced to the center of the reticle, offsets may exist between the center element and the reference dot. These can be taken into account by adding offset terms to the correction algorithm.[1] This procedure is followed in calculating the corrected x and

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[1]Section III of this report discusses the case where offsets exist and gives the actual algorithm used.

4
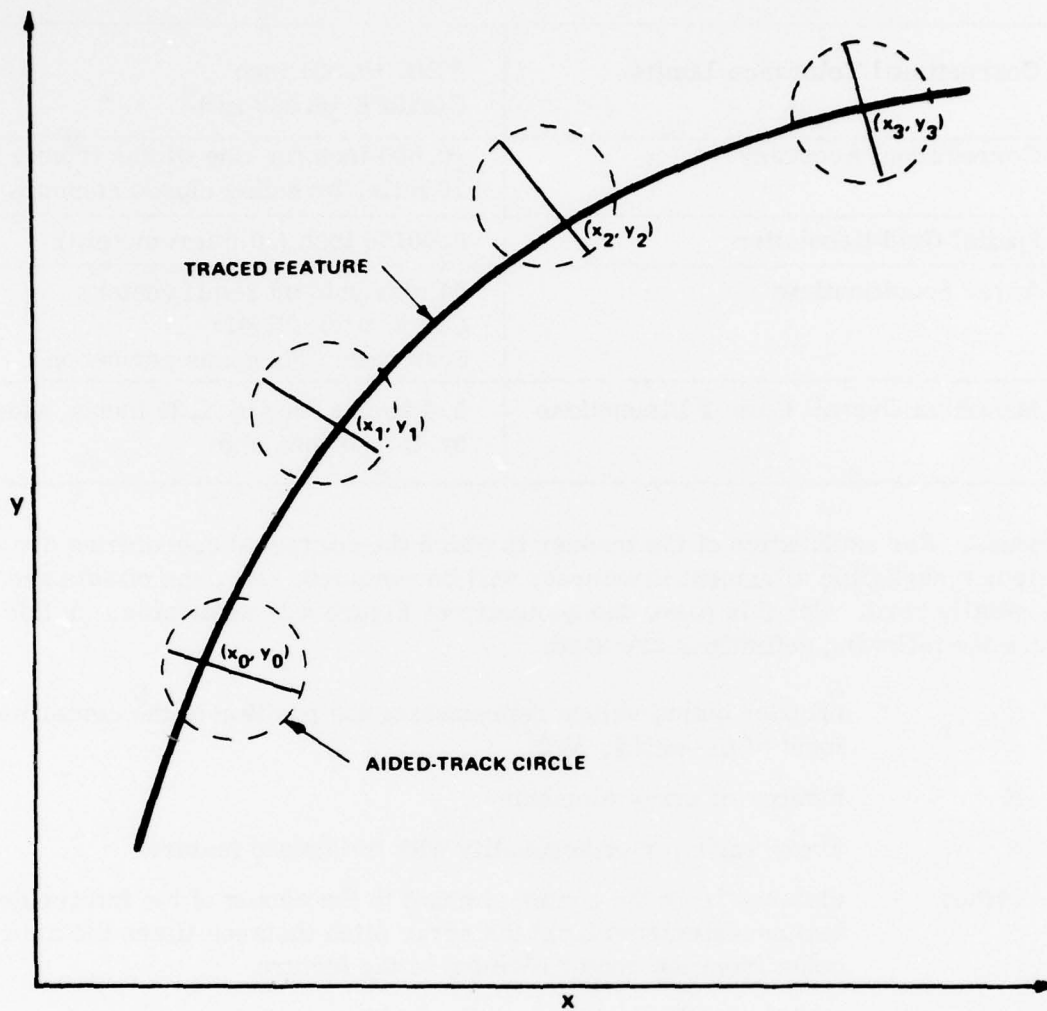
Figure 3. Orthogonal array tracing. Rotation of the array to remain orthogonal to the traced feature allows an accurate estimation of line position which is unaffected by feature curvature.

TABLE 1. SOME KEY SYSTEM PARAMETERS FOR
AIDED-TRACK CURSOR SYSTEM

Correctional Tolerance Limits	FINE $\pm$0.031 inch COARSE $\pm$0.053 inch
Correctional Accuracy	$\pm$0.004 inch for line widths from 4 to 20 mils, including closed contours
Spatial Grid Resolution	0.00156 inch (40 micrometers)
Array Specifications	64 elements on 2-mil centers Clock rate: 25 kHz Scan rate: 362 scans per second
Maximum Overall Cursor Dimensions	5.4 inches long by 4.25 inches wide by 1.75 inches high

y values. For explanation of the manner in which the corrected coordinates are generated, a negligible alignment inaccuracy will be assumed, i.e., the offsets are essentially zero. For this case, the geometry of Figure 4 is applicable. In this figure the following definitions are used:

x_e, y_e encoder output values representing the position of the center element of the array, $N/2$

N number of array elements

θ array angle for orthogonality with the traced feature

ρ(rho)   distance from the center element to the center of the intercepted feature calculated from the array pitch distance times the array count from the center element to the feature

x, y actual coordinate values of the feature

Δx, Δy errors in actual feature coordinates with respect to encoder outputs.

This geometry gives the true x, y values of the feature measured along the array axis as:

$$\text{True } x = x_e + \rho \cos \theta$$

$$\text{True } y = y_e - \rho \sin \theta.$$

Values x and y are the corrected values calculated by the system.

INTERPOLATED CURSOR CROSS-HAIR

TRACED FEATURE

ARRAY

θ

X_e, Y_e

Δx

Δy

$\dfrac{N}{2}$

ρ

X, Y (TRUE POSITION)

N

Y

X
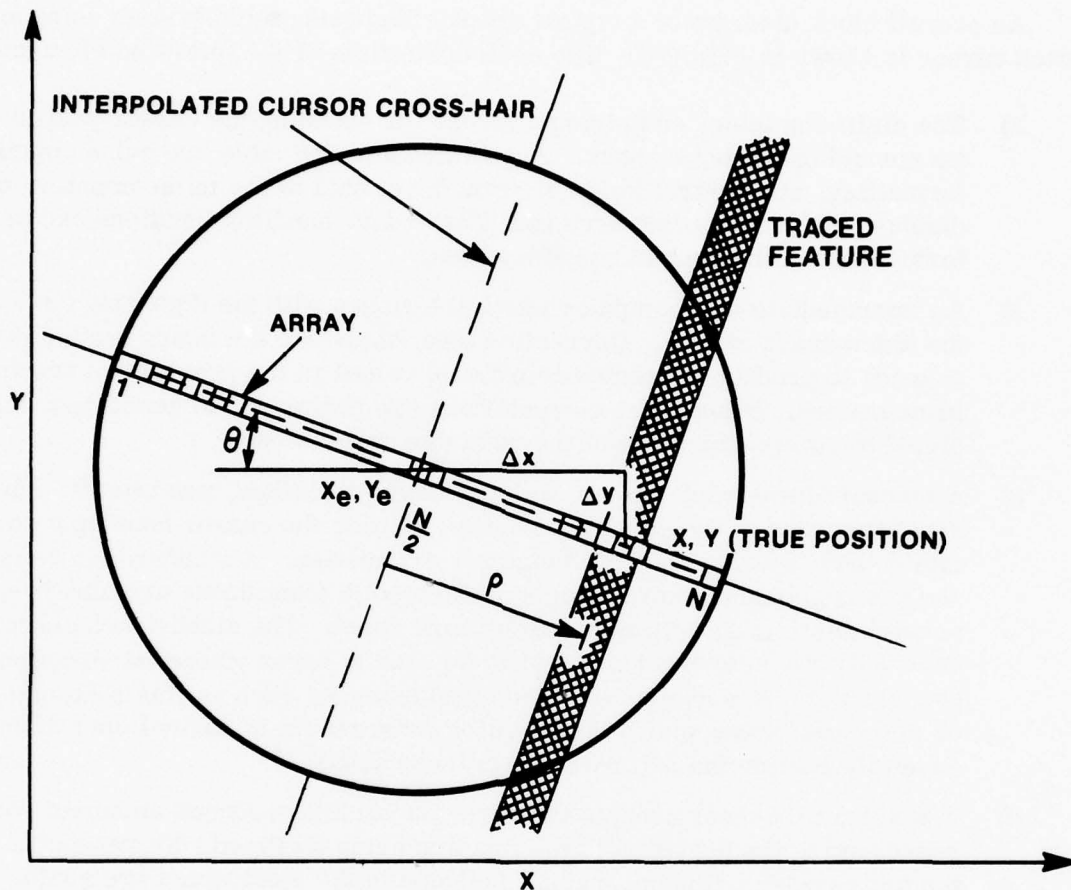
TRUE X $= X_e + \Delta x$ where $\Delta x = \rho \cos\theta$

TRUE Y $= Y_e - \Delta y$ where $\Delta y = \rho \sin\theta$

Figure 4. Geometry for computing correction factors to modify encoder output.

The encoder values for this point and the last previous point are then used to recalculate angle θ by determining the tangent of the path taken by the cursor with respect to the y-axis. The angle is updated at every data point in this manner as the feature is followed. Initial orientation is established by an accurate track of the first two points of the feature.

Details of the computational algorithm may be found in Section III of this report. The algorithm contains provision for angle smoothing and offset corrections, and is compatible with the Lineal Input System (LIS).

7

D. OVERALL SYSTEM OPERATION IN AIDED-TRACK MODE

An overall block diagram of a typical graphic digitizing table system using an aided-track cursor is shown in Figure 5. The system consists of the following elements:

1) The digitizing table, containing a means for encoding the cursor position in its normal operating manner. Associated with the table are pulse counting, formatting, and control logic for transfer of data to the minicomputer, or to display and/or recording devices. These data-handling functions are performed within the control console shown.

2) An intermediate minicomputer which interfaces with the digitizing table and the aided-track cursor. Correction algorithms use the inputs from these sources to produce corrected coordinate values in the presence of tracing inaccuracies. In addition, computations are performed to generate a command signal to control the angle of the rotatable array mount.

3) A manual aided-track cursor, as previously described, produces a high-rate repetitive scan of the photodiode array. Within the cursor housing a servoed motor drive system controls the array orientation. A standard digitizing cursor has pushbutton controls for mode selection (continuous or point-by-point manual digitizing), editing functions, and reset. The aided-track cursor is provided with an override control to be used in areas where intersections of graphic features occur or in other circumstances such as fine contouring or congested areas where the operator must resort to normal operations, carefully tracing the feature through these areas.

4) The video processor accepts the array output and produces an output count representing the deviation of the function being digitized with respect to the table encoder fiducial mark. Included in the electronics are analog threshold and gain adjustments to accommodate variations in table illumination characteristics such as shading and intensity. The digital counter logic employed is designed to produce a count representing the best estimate to the center of the intercepted function, which may cover several array elements. The output of the video processing chain is continuously transferred to the computer for correcting the table encoder values as they are entered at discrete motion intervals.

5) The array video control contains the circuitry for generating timing signals and phase clocks for the self-scanned array. The electronic circuitry provides for adjustments in scan rate and in scan period, allowing control of the array integration time for developing adequate signal modulation levels to ensure positive detection.

6) The array rotation servo contains a digital-to-analog converter to generate the motor drive signal, and the compensation and drive amplifiers for the servo position loop.

8
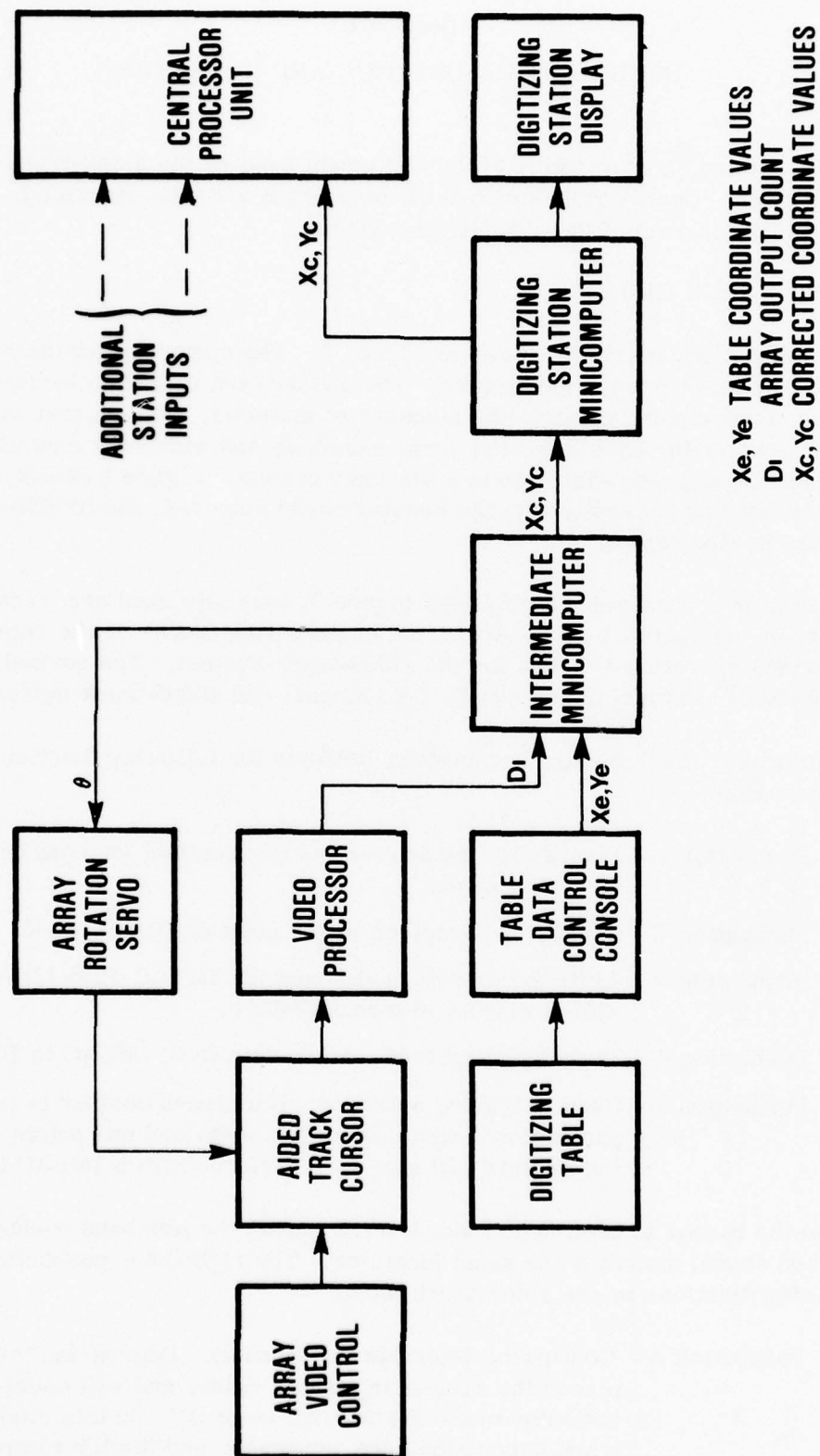
Figure 5. Block diagram of aided-track cursor digitizing system.

CENTRAL PROCESSOR UNIT

ADDITIONAL STATION INPUTS

DIGITIZING STATION DISPLAY

DIGITIZING STATION MINICOMPUTER

INTERMEDIATE MINICOMPUTER

ARRAY ROTATION SERVO

VIDEO PROCESSOR

TABLE DATA CONTROL CONSOLE

AIDED TRACK CURSOR

DIGITIZING TABLE

ARRAY VIDEO CONTROL

Xc, Yc

Xc, Yc

Dᵢ

Xe, Ye

θ

Xe, Ye   TABLE COORDINATE VALUES
Dᵢ   ARRAY OUTPUT COUNT
Xc, Yc   CORRECTED COORDINATE VALUES

9

Section II

EQUIPMENT DESCRIPTION AND OPERATION

In this section, a description of the equipment used in the aided-track cursor system is given. Operational functions of the system are also described. Figure 6 gives the block diagram of the aided-track system.

A. AIDED-TRACK CURSOR

The aided-track cursor is shown in Figure 7. The operator viewing port on the front cover is used to trace the feature. The aided-track reticle is located in the bottom of the viewing port, close to the manuscript material. This cursor is constructed by attaching a housing containing the array assembly and additional control pushbutton switches for aided-track operation to a standard cursor. Figure 8 shows a view of the aided-track cursor assembly with the housing cover removed; the identification of the components is also shown.

The station control pushbuttons (see Figure 7) normally used are on the left side of the cursor, numbered 1 to 5. Additional control pushbuttons on the right side select various operational modes for the aided-track system. The normal station control pushbuttons perform identically in both normal and aided-track modes of operation.

In summary, the left-hand pushbuttons perform the following functions in normal station operation:

      Pushbutton 1 – Places the Gradicon in the incremental (or continuous) digitizing mode.

      Pushbutton 2 – Places the Gradicon in the point digitizing mode.

      Pushbutton 3 – Calls for an edit mode from the IMLAC PDS-1D which allows display of traced feature.

      Pushbutton 4 – Transfers digitized feature data from IMLAC to PDP-15.

      Pushbutton 5 – Used in tracing contours. If a closed contour is traced, pushbutton 5 will ensure that start and end points coincide. Data points will also be transferred from IMLAC to PDP-15.

When the cursor is used in the aided-track mode, the left-hand pushbuttons (1 to 5 described above) maintain the same functions. The right-hand pushbuttons perform the following functions in the aided-track mode:

      Pushbutton A – Continuous Override (or Manual). Depressing this pushbutton places the system in manual mode, and will cause the LED indicator marked MANUAL to go ON. In this mode the aided-track corrections are bypassed, and the HP computer merely

10
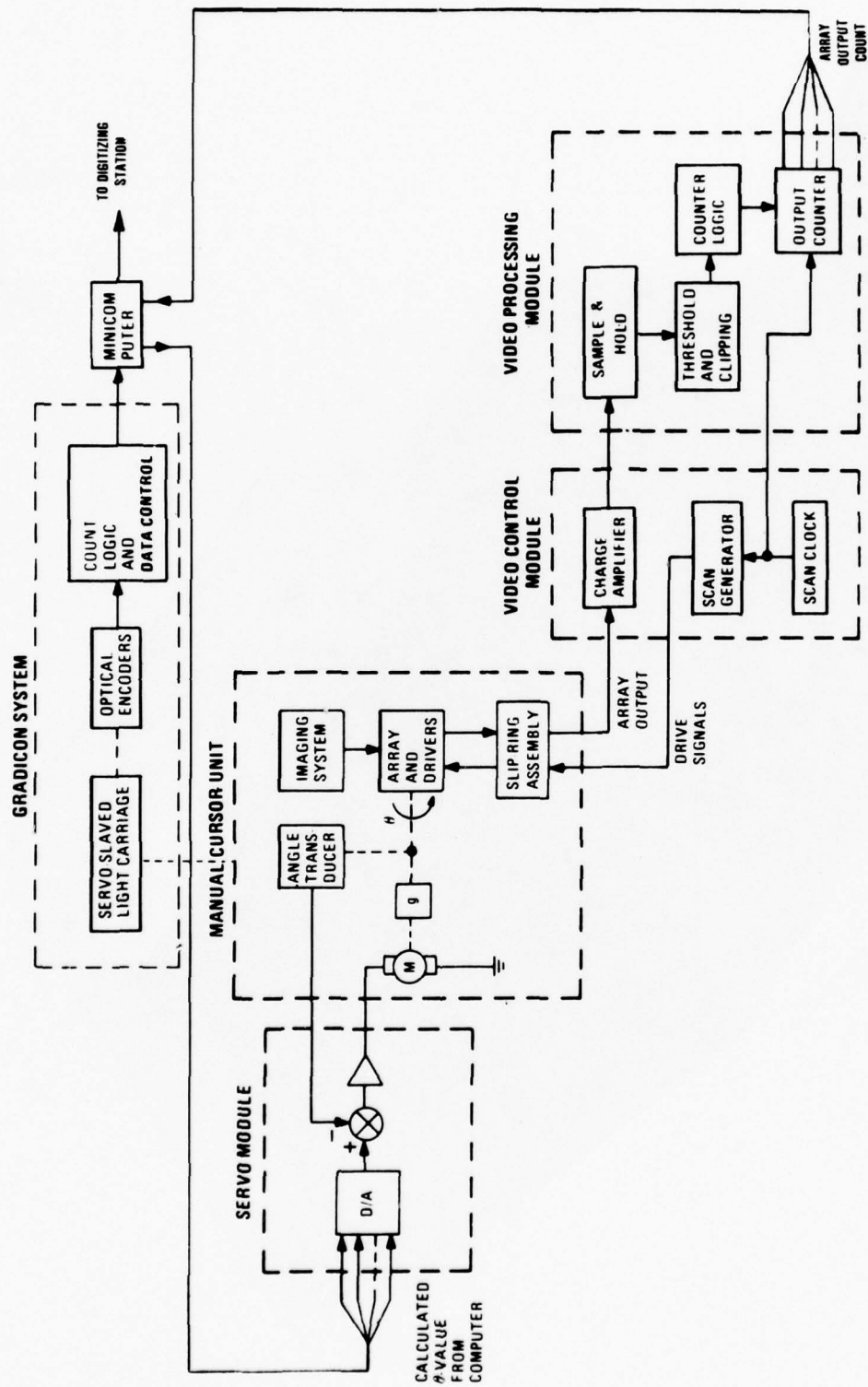
Figure 6. Block diagram of the aided-track cursor system showing functional units.

11
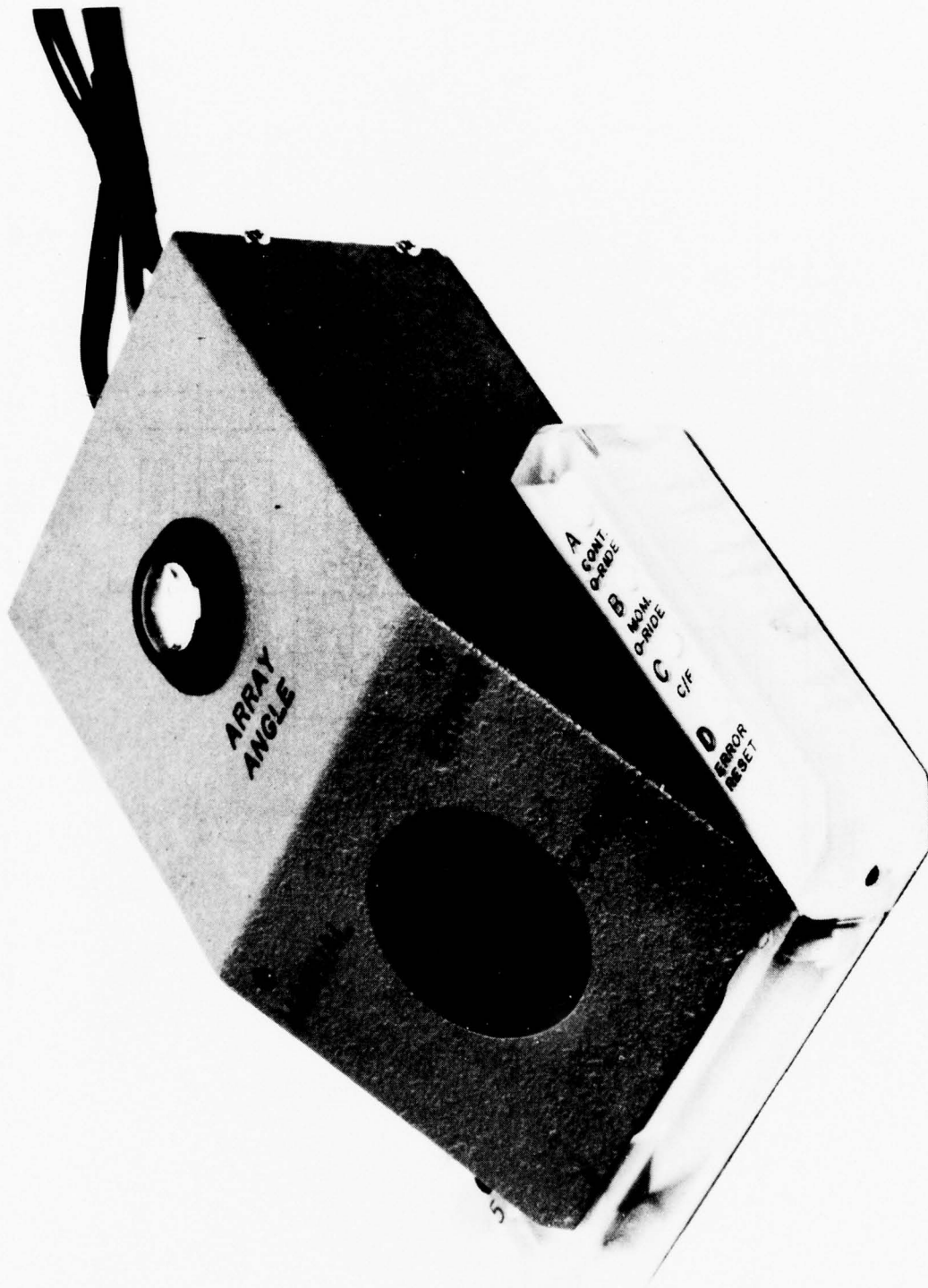
Figure 7. Photograph of aided-track scanning cursor. Scale approxdmately 1.25-to-1.

12
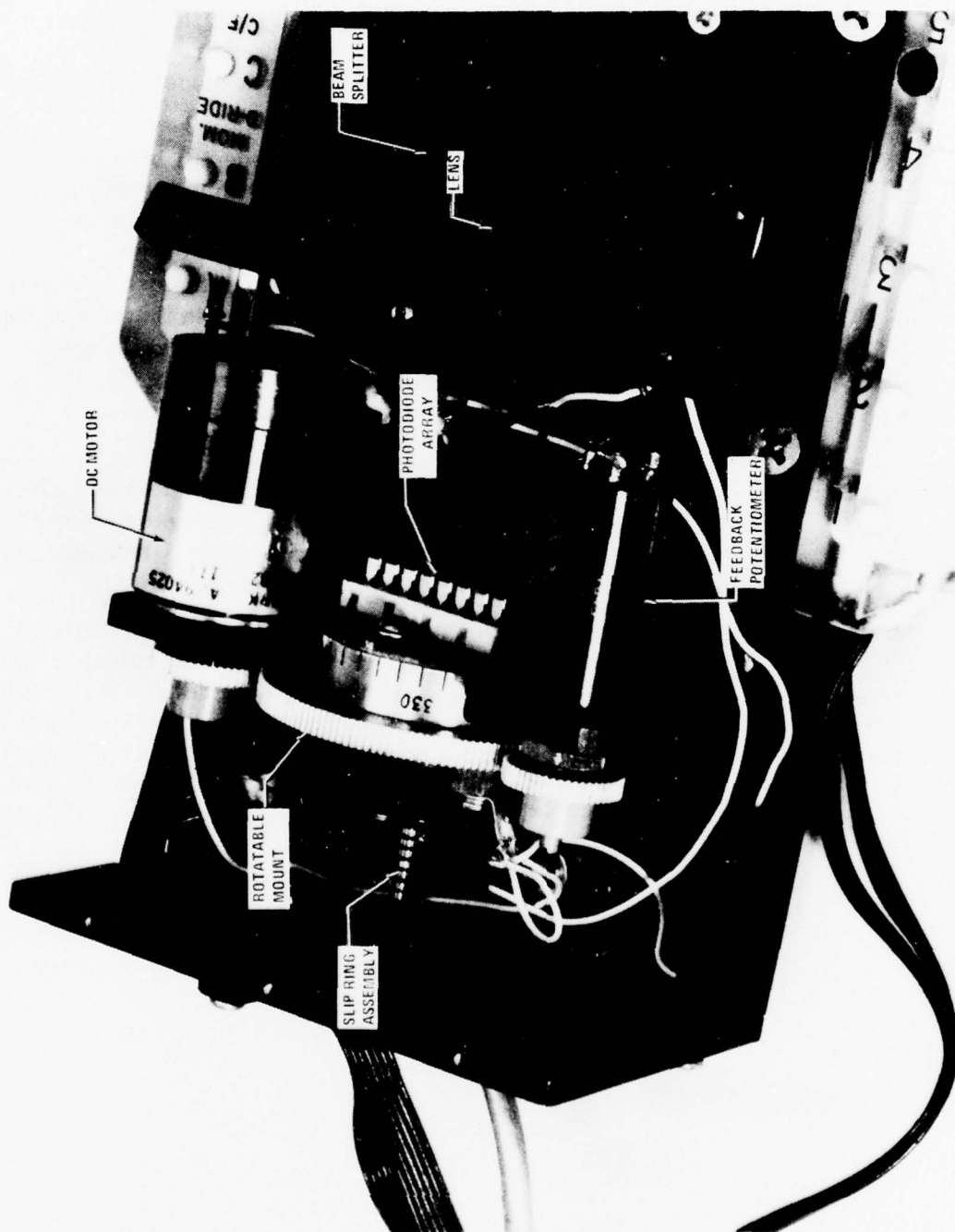
Figure 8. View of scanning cursor mechanical arrangement.

relays Gradicon data to the IMLAC as in "normal" station operations. Digitizing accuracy depends upon the operator's ability to maintain the cursor cross-hair on the feature. Data points from the Gradicon console are used, however, to update the angle commands to the array rotation servo to maintain orthogonality of the array to the feature so that the system can be placed in an aided-track mode without initializing the angle.

Pushbutton B – Momentary Override. The manual mode can be entered for short periods of time by depressing and holding down this pushbutton; the manual indicator will go ON during the interval the pushbutton is held down. This provision is made so that the operator can traverse through feature intersections or other short areas of confusion as in the manual mode. Upon release of the pushbutton, the aided-track mode is again initiated. As in the continuous manual mode, the array angle is updated during the time the momentary override button is depressed.

Pushbutton C – Coarse/Fine Select. Depressing this pushbutton will alternately select either the larger (coarse) diameter aided-track circle or the smaller (fine) diameter circle. Indicator lights on the cursor show which mode is selected.

Pushbutton D – Error Reset. If the limits of the selected aided-track tolerance circle have been exceeded, the error indicator will remain ON continuously, even though the reticle position has been returned to within the correction limits. The error indicator can be extinguished only by realigning the feature within the selected aided-track circle, and by depressing the error reset pushbutton. This indicates to the operator that perhaps an edit is called for to determine the extent of the error, and to retrace if necessary.

If the error light remains ON continuously with the feature well within the circle, the computer program is halted and no data is transferred to the IMLAC. This condition will exist until the indicator can be turned OFF by the error reset pushbutton.

The error indicator will light when the limits of correction are being approached; however, as the feature is returned toward the center of the reticle, the error indicator will automatically reset. If this automatic reset occurs, all data taken during the interval when the indicator was ON is valid. This error-indicating mode serves only to alert the operator that he is approaching the end of the allowable error tolerance, and that his trace should be returned further into the selected tracing circle.

This completes the functional description of the cursor control pushbutton switches and their associated indicators located on the cursor housing.

B. VIDEO PROCESSOR

The video processor shown in Figure 9 accepts the array video output and converts the sample number at which the array detects a feature to a binary count. This count is then transferred to an intermediate computer where correction factors are generated.

Two plugs (J2 and J3) on the left side of the unit supply the array via ribbon cables with power and the required array scan control signals (start pulse, 2-phase drive pulse trains, and clock pulses), and rotational drive commands. A low-capacitance shielded cable returns the array video output to the lower connector. (All required electronics other than those located on the cursor itself are housed in the video processor. These electronics include array scan control circuitry and the array rotation servo circuitry. The unit is completely self-contained, providing +5 V dc and +15 V dc from modular power supplies. Primary power is supplied from a 60 Hz, 117 V line.)

The front panel meter monitors the output of the array gain amplifier. When the cursor is used on a number of tables, the meter output will indicate differences in brightness of the illumination sources. The ARRAY GAIN is used to increase or decrease the array output to a reference level within the amplifier operational limits.

15
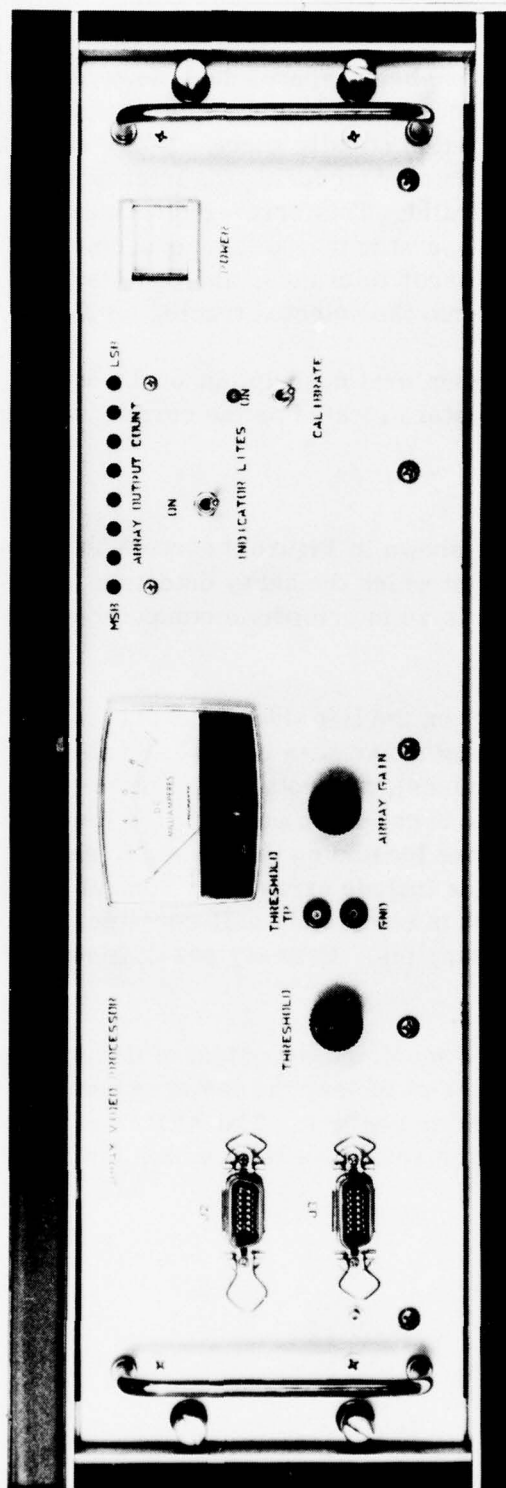
Figure 9. Front panel view of video processor.

16

The array output count is shown on an 8-bit LED indicator. These indicator lights can be turned ON or OFF by the indicator light switch shown.

To determine offset distances (Δx and Δy) between the array rotational center and the reticle center dot, the calibration switch in Figure 9 is used. In the ON position the operator has provision for programming the array for 0° and 90°, necessary for determining Δx and Δy from the array output count. For this procedure, orthogonal lines are used as features, with the reticle dot centered on the lines.

An ac power switch for the unit is located in the upper right corner.

Rear panel adjustments and test points available are:

1) θ-scale factor potentiometer (adjusted for 51.2^o per volt)

2) D/A zero adjust

3) Servo gain

4) Servo ON-OFF (switch)

5) θ-adjust (zero adjustment).

Test points are brought out on a monitor plug, and may be used to monitor:

1) Count output

2) Blanking pulse

3) D/A output.

For an understanding of the gain and threhold adjustments located on the front panel, a simplified diagram of the analog processing of the array signal is shown in Figure 10. Waveforms are also shown in this figure at various points, with explanatory notes. In following the procedure for adjustment of the balance and threshold levels, the necessary controls and monitor test points are available on the front panel:[1]

1) With an oscilloscope on the BAL AMP test point, adjust the array gain and balance potentiometers until the detected signal is a clean negative-going waveform as shown in Figure 10 (B).

---

[1] During tests the BALANCE AMPLIFIER OUTPUT test point and BALANCE AMPLI-FIER ADJUST potentiometer were added to the front panel for setup convenience. These are not shown in Figure 9, which was made prior to the changes. Reference is made to these points in the text in describing operational adjustments.

ARRAY GAIN

DC BALANCE AMPLIFIER

TBS
220K
R11*

ARRAY SIGNAL

+.2
0

2K

22K

Z8
−
+
741

Ⓐ

4.7K

TBS
100K
R15*

F/P TP

Z9
−
+
741

Ⓑ

2.2K

Ⓒ

3.6 V

THRESHOLD COMPARATOR

F/P TP

Z15
−
+
710

Ⓓ

Z16
7400

GAIN F/P

−6.2 V

3.3K

2.5K

BALANCE ADJ F/P
$\overline{e}_{BAL}$ = −2.7 V

−15 V

4.7K

1K

$\overline{e}_{TH}$ =−2.6V

THRESHOLD ADJ F/P
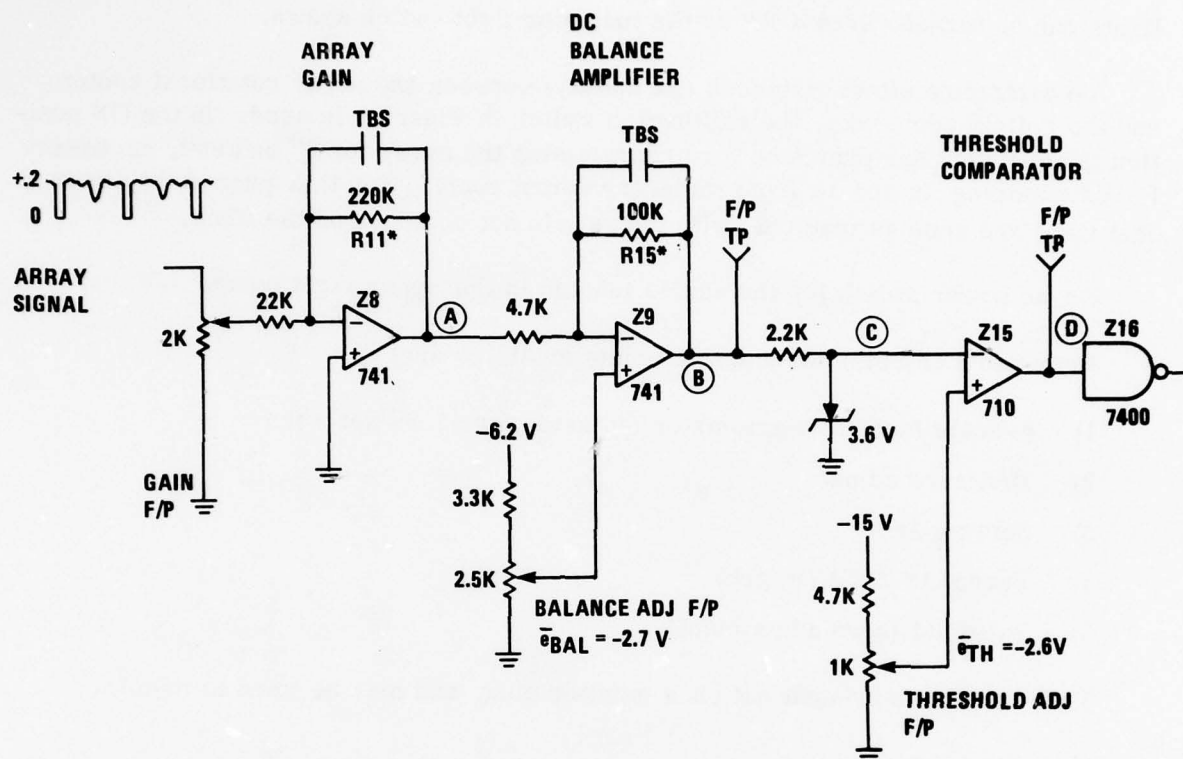
WAVEFORM DIAGRAMS OF ANALOG PROCESSING

Ⓐ   0   t
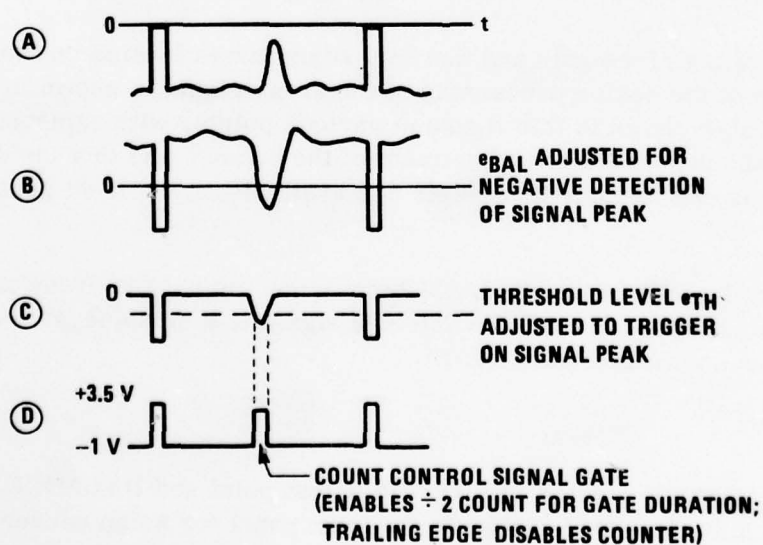
*R11 & R15 SELECTED FOR AVAILABLE LIGHT LEVEL

Ⓑ   0 e_{BAL} ADJUSTED FOR NEGATIVE DETECTION OF SIGNAL PEAK

Ⓒ   0   THRESHOLD LEVEL e_{TH} ADJUSTED TO TRIGGER ON SIGNAL PEAK

Ⓓ   +3.5 V   −1 V

COUNT CONTROL SIGNAL GATE (ENABLES ÷ 2 COUNT FOR GATE DURATION; TRAILING EDGE DISABLES COUNTER)

Figure 10.   Analog processing section of video processor unit.

18

2) With the oscilloscope on the THRESHOLD test point, adjust the threshold potentiometer until a clean pulse is observed for the detected signal as shown in Figure 10 (D).

Since the shading of the illumination source will vary with array angle and may cause spurious detections, several angles should be examined, and the adjustments given above should be made to accommodate the worst-case condition. Only angles from 0° to 180° need be examined.

Photographs of various waveforms are shown in Figure 11 for a 5-mil line.

C. COMPUTER

The processor used with the aided-track cursor is from the Hewlett-Packard 21 MX computer series and consists of an HP 2105A processor and an HP 2102A memory system. Specifications for this system are given in Table 2.

The units comprising the aided-track cursor system are shown in Figure 12.

AMPLIFIED ARRAY OUTPUT FOR 5-MIL LINE 10V/CM

SCRIBED AIDED-TRACK CIRCLE DETECTIONS

THRESHOLD COMPARATOR OUTPUT

÷ 2 GATE ENABLE

COUNT OUTPUT
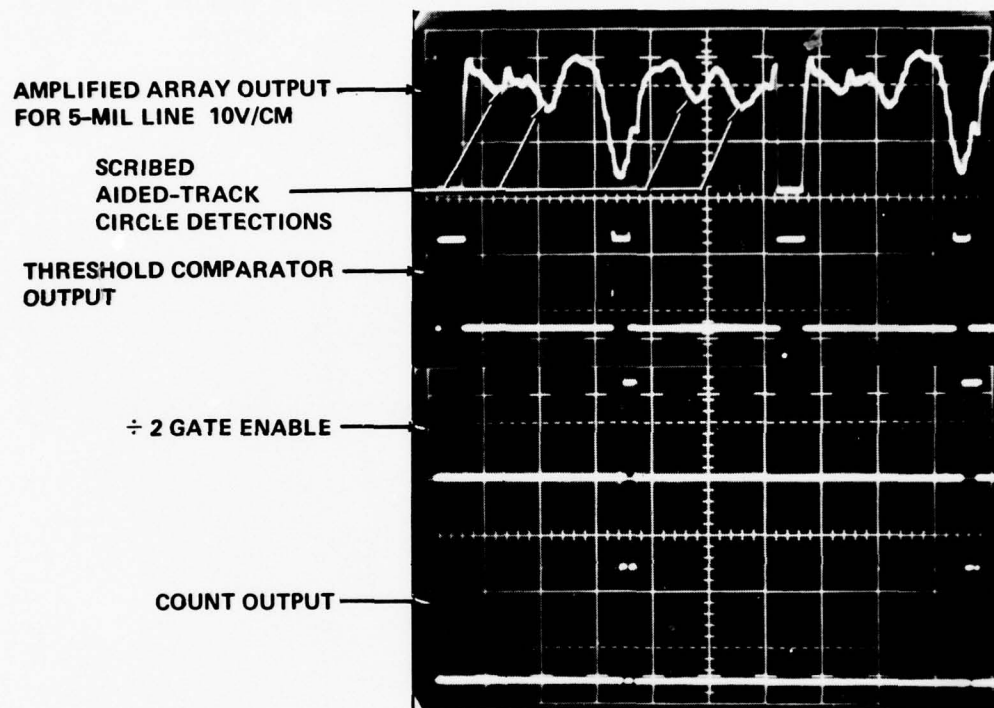
Figure 11.   Typical waveforms in the video processor chain.   Coarse mode.

20

TABLE 2. SPECIFICATIONS FOR HEWLETT-PACKARD COMPUTER

PROCESSOR
  CONTROL STORE
    Type: Bipolar LSI ROM semiconductor.
    Size: Up to sixteen 256-word modules.

  CONTROL PROCESSOR
    Address Space: 4,096 words.
    Word Size: 24 bits.
    Word Formats: Four.
    Word Fields: Five.
    ROM Cycle: 325 nanoseconds.

  REGISTERS
    Accumulators: Two (A and B), 16 bits each. Explicitly addressable; also implicitly addressable as memory.

    Index: Two (X and Y), 16 bits each.
    Memory Control: Two (T and P), 16 bits each; one (M) 15 bits.

    Supplementary: Two (overflow and extend), one bit each.
    Manual Data: One (display), 16 bits.
    Scratch Pads: Twelve, 16 bits each.

  MEMORY PARITY CHECK
    HP 2105A Processor: Monitors all words read from memory. Switch selectable to either halt or ignore parity when detected. A parity indication is displayed on operator panel.

  POWER FAIL INTERRUPT
    Priority: Highest priority interrupt.
    Power Failure: Detects power failure and generates an interrupt to trap cell for user-written power-failure routine. A minimum of $500 \mu s$ is available for the routine. Automatic restart is provided as a memory system option.

TABLE 2 (Continued)

PROCESSOR (cont.)
  PROTECTION
    Loaders:
           All loaders reside in special ROM's separate from control ROM and are loaded into last 64 words of logical main memory by activating operator panel switches. Paper tape loader is standard; three additional switch-selectable loader spaces are provided to accommodate other modes of operation as a user option. User-generated loaders may be written in Assembly Language.

    Volatility:
           Mains ac standby mode and sustaining power for line loss of 2.5 cycles at 60 Hz before entering power fail routine. Power fail recovery is a memory system option.

  INPUT/OUTPUT
    Priority Interrupt:
           Multilevel vectored priority interrupt determined by interface channel assignment.

    I/O Channels:
           HP 2105A: four internal I/O channels.

    Current Available to I/O:

SUPPLY	HP 2105A
+5 V	6.0A
-2 V	2.0A
+12 V	1.0A
-12 V	1.0A

Note: Current availability to I/O assumes maximum memory in mainframe, Dual-Channel Port Controller, and maximum available control store mounted to CPU.

PHYSICAL CHARACTERISTICS
  Width:
           16-3/4 inches (42.55 cm) behind rack mount; 19 inches (48.26 cm) operator panel width on sides.

  Depth:
           23-1/2 inches (59.69 cm); 23 inches (58.42 cm) behind operator panel.

  Height:
           HP 2105A: 5-1/4 inches (13.31 cm) in rack mount.

  Weight:
           HP 2105A: 39 pounds (17.69 kg).

TABLE 2 (Continued)

PROCESSOR (cont.)
  ELECTRICAL CHARACTERISTICS
    Input Line Voltage: 110 V or 220 V ac (±20%), single phase.
    Line Frequency: 47 to 66 Hz.
    Power: HP 2105A: 400 W maximum.

    Line Overvoltage Protect: Input crowbar in series with line breaker.
    Output Protect: All voltages protected against overvoltage
                                    and overcurrent.
    Output Voltage Regulation: +5%.
    Thermal Sensing: Monitors internal temperature and auto-
                                    matically shuts down if temperature ex-
                                    ceeds specified level.

MEMORY SYSTEM
  HP 2102A MEMORY
    Density: Medium or high density.
    Configuration: 8K.

  MEMORY ORGANIZATION
    Type: 4K chip N-channel MOS/RAM semiconductor.
    Word Size: 16 bits plus parity bit.
    Configuration: Controller and multiple plug-in memory
                                    modules.
    Page Size: 1,024 words.
    Address Space: 1,048,576 words.
    System Cycle Time: 650 nanoseconds.
    Volatility Protection: Mains ac standby mode and sustaining
                                  power for line loss of 160 milliseconds
                                  is standard. Power fail recovery system
                                  is optional.

HP MINICOMPUTER

VIDEO SIGNAL PROCESSOR
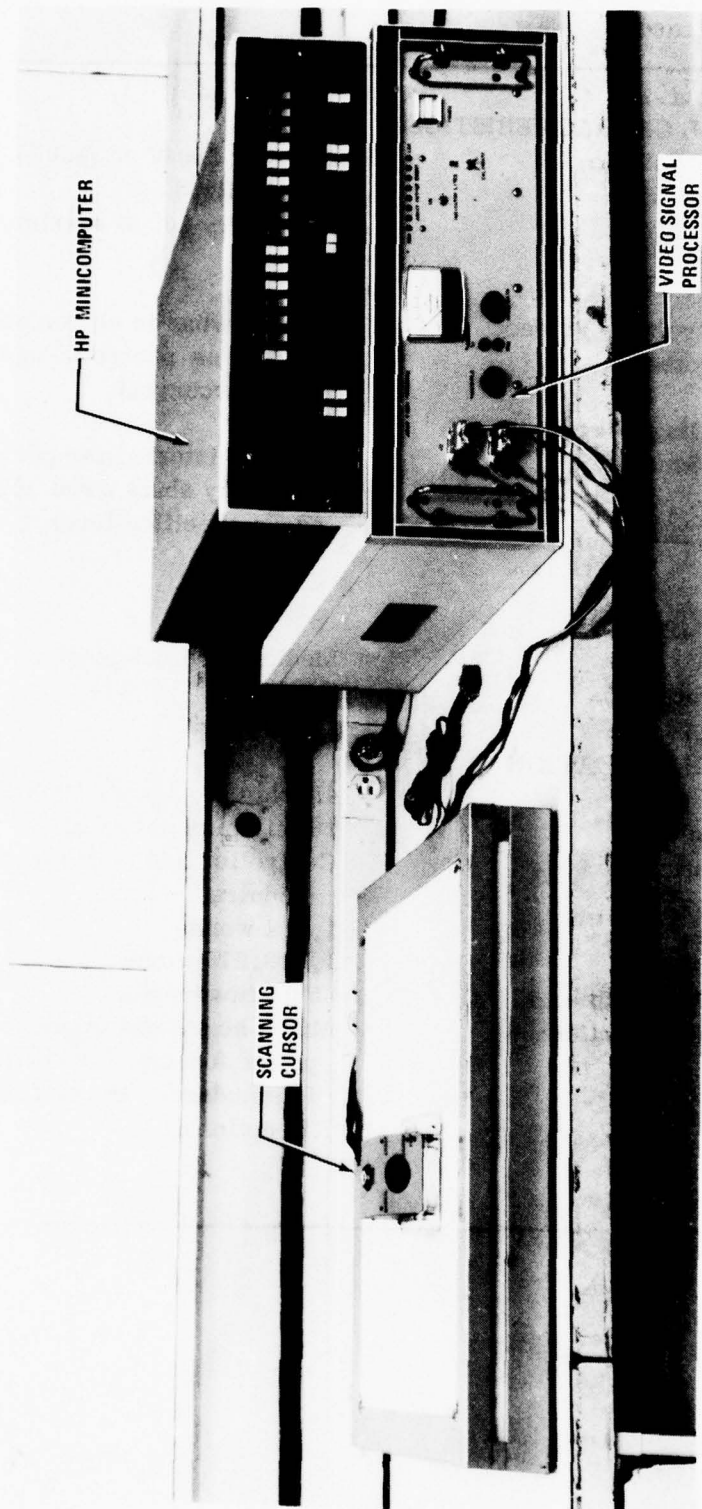
SCANNING CURSOR

Figure 12. Overall view of scanning cursor system.

24

Section III

COMPUTER CORRECTION ALGORITHM AND COMPUTER FUNCTIONS

A. GENERAL COMMENTS

The program for the Hewlett-Packard HP21MX computer has four main functions:

1) To obtain the x data, the y data, and the status word from the Gradicon unit.

2) To correct the x data and the y data for any errors in tracking.

3) To pass the corrected x data, y data, and status word to the IMLAC PDS-1D computer.

4) To compute the angle required to maintain the array normal to the curve being tracked.

The program must also provide for the calibration of the cursor, must initialize the system at the beginning of the digitizing of a feature, and must provide auxiliary subroutines for the testing and debugging of the program and of the equipment.

B. GRADICON DATA INPUT

The Gradicon data output is in the form of three 16-bit parallel binary words: one for the x coordinate of the digitizing table, a second for the y coordinate, and a third for the status word. The status word defines the condition and type of the data being transferred, and transmits commands from the cursor to processing units further along the chain, such as the IMLAC PDS-1D or the PDP-15. The dimensional units of this data are determined by a thumb wheel on the front panel of the Gradicon console and are variable from 10 micrometers to 100 micrometers in steps of 10 micrometers. In operation with the LIS system, this resolution is normally maintained at 20 micrometers per Gradicon digit.

The signs of the x data and the y data are carried in Gradicon bits 8 and 9 (HP bits 7 and 6) of the status word. The program for the Hewlett-Packard Computer contains provision for handling negative data and for handling 16 bits of data, although the Hewlett-Packard computer internally uses the 16th bit as the sign bit. The LIS system will not handle negative data. Therefore, some of these provisions have never been tested in actual practice.

The HP computer requests the status word, the x word, and then the y word, in that order, and stores the data in memory locations. If the unit is in manual mode, the data is immediately transferred to other memory locations for transmission to the IMLAC. In automatic mode, the data is corrected for tracking error before it is transmitted to the PDS-1D.

25

C. TRACKING ERROR CORRECTIONS

As discussed earlier, the array determines the location of the center of the line in array counts and passes this count to the computer. As counts outside the reticle circle are eliminated in the video processor, the center of the array when in perfect alignment is on the 27th element for the coarse mode and on the 16th for the fine mode.

The array count data, i.e., RHO in the program, is transmitted to the computer as bits 0-6 of an 11-bit word. Bits 7, 8, 9, and 10 represent start-of-feature, coarse mode, automatic mode, and calibrate mode, respectively; three bits are controlled by pushbuttons on the cursor, while the bit for calibrate mode is controlled by a switch on the front panel of the video processor.

The correction factors to correct the Gradicon data for tracking errors are calculated by the following formulas:

$$X_c = RC \cos \theta$$

$$Y_c = -RC \sin \theta$$

where

$$R = (\rho - A_c) - (X_0 - A_c) \cos \theta + (Y_0 - A_c) \sin \theta$$

$$C = 24.5 \, S/W$$

and where

X_c = DELX = X coordinate correction

Y_c = DELY = Y coordinate correction

θ = THETA = angular position of the array measured clockwise from the horizontal

ρ = RHO = array reading, in array counts

A_c = ACN = center of rotation of array, in array counts

X_0 = XCFC = location of center of reticle along x axis, in array counts

Y_0 = YCFC = location of center of reticle along y axis, in array counts

C = CONST = conversion of array counts to Gradicon units

26

S = SPAC = array spacing, in mils

W = RESOL = Gradicon resolution, in micrometers.

The labels following the symbols for the variables are the mnemonic labels by which these variables are identified in the program listing.* Variables A_c, X_0, and Y_0 have different values for coarse mode and fine mode. THETA is obtained from the array angle calculation which is discussed in Section F below.

These formulas may be derived as follows (Figure 13 represents a line being tracked by the array whose axis is along the line A-Z):

Let B = projection of the center of rotation of the array R_c on the array. This point does not move as the array rotates.

Let F = location of center line of curve being tracked, normal to the array.

Let $\overline{AB}$ = A_c = ACN = center of array rotation, in array counts

Let $\overline{AF}$ = ρ = RHO = array reading, in array counts

Let O = center of coordinate system which is centered on the axis of the cursor reticle.

Then:

$$\overline{CF} = \overline{OF}' = R = \text{distance from origin to line}$$

$$X_0 = XCFC = (\overline{OD} + \overline{AB}) = (\overline{AO} \text{ when array is parallel to the x axis})$$

$$Y_0 = YCFC = (\overline{OE} + \overline{AB}) = (\overline{AO} \text{ when array is parallel to the y axis})$$

Let X = $\overline{OG}$ = projection of OF' on x axis = $R \cos \theta$

Let Y = $\overline{OK}$ = projection of OF' on y axis = $-R \sin \theta$

Then, by geometry:

$$R = (\rho - A_c) - (X_0 - A_c) \cos \theta + (Y_0 - A_c) \sin \theta$$

Then:

$$X_c = DELX = CX = RC \cos \theta$$

$$Y_c = DELY = CY = -RC \sin \theta$$

where C converts array counts to Gradicon units. The negative sign for Y_c results from the clockwise rotation of the array.

---

*The program listing may be found in the computer program documentation on this contract.

Figure 13. Geometry of computer correction algorithm.

The output data to the IMLAC is derived from these formulas via the following:

$$X_I = X_g + X_c$$

$$Y_I = Y_g + Y_c$$

where
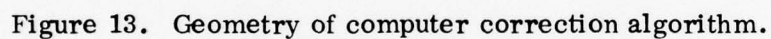
$$X_I = X1 = \text{X data output to IMLAC}$$

$$Y_I = Y1 = \text{Y data output to IMLAC}$$

$$X_g = \text{XWIN} = \text{X data from Gradicon}$$

$$Y_g = \text{YWIN} = \text{Y data from Gradicon.}$$

D. VECTORING

In trace or incremental mode operation, the IMLAC PDS-1D places the following requirements on the displacement in x and in y between the last received data point and the current data point (these requirements are inherent in the LIS system):

1) Both the x and y displacements must fall between -2 and +2 Gradicon output units, inclusive.

2) The absolute value of at least one of the displacements must equal 2.

The data received by the HP computer from the Gradicon satisfies these criteria. However, because of the correction process, the output points may not. Therefore, the program must assure that these criteria will be satisfied. The program assumes that over a space of two output points, the curve being traced can be approximated by a straight line, which passes through the last data point and the current data point. A new point on that line is found which, along the coordinate with the greatest displacement, has a displacement of two in the same direction as the original displacement. Since this is the coordinate of greatest absolute displacement, the other coordinate, when calculated, will have an absolute displacement of less than two and the initial requirements will be fulfilled.

This correction is made only when the cursor is in the Automatic, Incremental mode. In practice, it has been found that this correction causes a change in a coordinate of one Gradicon resolution element at most. It is self-correcting in that if the vector is elongated at one correction, it will probably be compressed at the next, as the input points before correction had the correct spacing.

E. OUTPUT OF DATA TO IMLAC

As discussed in Section C, the corrected coordinate data X_I and Y_I are stored in memory locations X1 and Y1. The status word is stored in location STATW. It was understood, in discussions with personnel from IMLAC Corporation, that data could be requested in any order. However, the last data requested must be the Y word, as the completion of this word sets the flag bit, thereby informing the source of data that the data required had been received. Therefore, special provision was made to store the data in three registers before informing the IMLAC PDS-1D that data was ready.

F. ARRAY ANGLE CALCULATION

The maintaining of the cursor array normal to the curve being tracked is a basic premise of the cursor operation. The array angle is controlled by a servo system in the video processor. The input to this servo system is a D-to-A converter which converts digital information from the computer into voltage information for the servo. The angle is transmitted to the D-to-A converter from the HP computer as a 10-bit word, each bit being 1°. When the array is horizontal, and in the center of its

29

tracking limits, the output is 512 decimal or 1000 octal. Maximum clockwise rotation is 1023 decimal or 1777 octal, while maximum counterclockwise rotation is zero.

In calculating the array angle, in the computer, the assumption is made that the angle whose tangent is the slope of the last two points tracked is a good approximation to the angle required. This assumption is justified as, in the extreme condition, when the line being tracked is on the outer circle of the reticle, an angular error of 17° will not cause the correction factor to shift by one array count. In the trace mode, where the cursor will have its real application, a curve with a radius of curvature of seven Gradicon resolution elements (5 mils in the normal operating mode) would be required to achieve this angle between points traced.

The slope of the line is determined directly from the coordinates of the last two points measured. The corresponding angle is determined from a tangent lookup table. The quadrant of the angle is determined from the sign of the x displacement and of the y displacement. At the start of a feature, the array is set to the midpoint (512°) to allow maximum excursion either clockwise or counterclockwise. As each new angle is calculated, the new angle is chosen so the array will have the least angular motion to reach that position.

G. ANGLE AVERAGING

In the incremental (trace) mode, the calculation of the slope from the last two points is subject to severe truncation errors. The displacements in x or y will always be one or two Gradicon units. This could cause angle errors as great as 45°. To minimize these errors, the average of the last eight angles measured is used to orient the array. The remaining fluctuation in angle is within the allowable limits necessary to maintain the required accuracy.

H. INITIALIZATION AND CALIBRATION OF SYSTEM

1) To load the program:

a) On the operator panel, set the key-operated switch to OPERATE.

b) Press left half or right half of register select switch to select the S-register.

c) Press CLEAR DISPLAY and set bits 6, 7, and 9 to ON.

d) Press STORE and press IBL.

e) Turn on the Teletype, and insert start of program in paper tape reader. If Teletype has been modified for use with the Hewlett-Packard computer, set the tape reader to Start.

f) Press PRESET and then press RUN. If the Teletype has not been modified to operate with the HP computer, set the tape reader to Start. The

30

program will now be read into memory, and the computer will halt when the program is loaded. A successful load is indicated if the Display Register contents are 102077 in octal (the condition of six lights in a row on the extreme right shows good load).

2) <u>To run the program:</u>

a) Press left half or right half of Register Select switch to choose the P-register.

b) Press CLEAR DISPLAY, and set bit 10 to ON.

c) Press STORE, PRESET, and RUN. The program will halt with the display showing two lights on the extreme right positions.

d) Press left half or right half of Register Select switch to select the S-register. The display will then show as a binary number the Gradicon resolution which was used last. If a different resolution is required, set it in the display, and push STORE. Push RUN. The program is now running. The Gradicon resolution is displayed when program is running.

3) <u>To calibrate the cursor:</u>

The reticle on the cursor is removable for cleaning and for replacement if it should become scratched. Therefore, it is necessary to be able to determine the location of the center of the reticle relative to the array. If this measurement is made along both the x and y axes, the position at any other point can be calculated. The geometry of this requirement was discussed in Section C above. When θ is zero, the array lies along the x axis (see Figure 13). The line $\overline{AC}$ will equal line $\overline{OD} + \overline{AB}$ or X_0 (XCFC) in the correction equation. The Y coordinate can be found in a similar manner.

To determine these values, the calibrate switch on the front panel of the video processor is turned ON. The computer will stop with its display showing three lights on the extreme right. The operator then accurately centers the array on a vertical line, sets the coarse/fine (C/F) pushbutton switch on the cursor to fine, and pushes the RUN switch on the left of the computer. The register will now show four lights on the extreme right. The coarse/fine switch is set to coarse and the RUN switch is pushed again. The register will then show five lights. The operator accurately places the cursor over a horizontal line, sets the coarse/fine switch to fine, and pushes the RUN switch. The display now shows six lights. The coarse/fine switch is set to fine and the RUN switch is pushed. The unit is now calibrated for reticle centering, and the calibrate switch should be turned OFF.

31

Included in the master program are subroutines and subprograms to do the following:

1) Write out X1, Y1, XWIN, YWIN on the Teletype on each cycle of the program.

2) Store X1, Y1, RHO, THETA, XWIN, YWIN. Up to 1000 data samples can be stored.

3) Write out the stored data on the Teletype.

4) Make a punched paper tape of the program in a format compatible with the HP program input procedures.

As these programs and subprograms are of use only for testing the hardware and debugging the program, they will not be discussed in greater detail in this report.

Section IV

SYSTEM TESTS AND RESULTS

A. ERROR STATISTICS OF MANUAL AND AIDED-TRACK TRACING

1. Manual Error Statistics

Figures 14, 15, and 16 show the error distribution for manual tracing of radial lines.

Figure 14 is for a radial line at an angle of +50 degrees with the horizontal axis. The histogram is composed of 127 points, having a standard deviation of 2.5 mils. The maximum and minimum error excursions shown are +4.7 mils and -6.3 mils, respectively.

Figure 15 is for a radial line at 0 degrees, and shows the distribution for 108 data points. Here the standard deviation was calculated as 2.91 mils, with a maximum error of +5.5 mils and a minimum error of -4.7 mils.

Figure 16 shows the results for a manual trace of a line at -140 degrees. The number of sample points used was 106; a standard deviation of 5.27 mils was calculated, with the curve showing maximum and minimum errors of +8.7 mils and -10.2 mils, respectively.

2. Aided-Track Error Statistics

Error statistics were also obtained by tracing radial lines in the aided-track mode. Results are shown in Figures 17 through 22.

Figure 17 is a histogram composed of 106 samples taken while tracing a +50 degree line. The standard deviation for these points is 1.82 mils; the curve shows a maximum error of 3.1 mils and a minimum of -4.7 mils, with one singular point at -7.1 mils.

The input data, i.e., the uncorrected data statistics for this case, are shown in Figure 18. Here the errors range from +12 mils to -14 mils, with a standard deviation of 5.2 mils.

Figure 19 shows the histogram for a traced line at 0 degrees, using 102 points. The standard deviation for this curve is 1.70 mils, with a maximum error of +4.7 mils (1 point) and a minimum of -3.9 mils (2 points). The remainder of the points are within +3.1 mils and -3.1 mils.

N = 127
θ = 50 DEGREES
σ = 2.54 MILS

ERROR, IN MILS

ABS	URD
19.6850	0.0000
18.8976	0.0000
18.1102	0.0000
17.3228	0.0000
16.5354	0.0000
15.7480	0.0000
14.9606	0.0000
14.1732	0.0000
13.3858	0.0000
12.5984	0.0000
11.8110	0.0000
11.0236	0.0000
10.2362	0.0000
9.4488	0.0000
8.6614	0.0000
7.8740	0.0000
7.0866	0.0000
6.2992	0.0236
5.5118	0.0000
4.7244	0.0236
3.9370	0.0394
3.1496	0.0551
2.3622	0.0866
1.5748	0.1260
0.7874	0.0866
0.0000	0.0630
-0.7874	0.1654
-1.5748	0.1102
-2.3622	0.0551
-3.1496	0.0787
-3.9370	0.0709
-4.7244	0.0157
-5.5118	0.0000
-6.2992	0.0000
-7.0866	0.0000
-7.8740	0.0000
-8.6614	0.0000
-9.4488	0.0000
-10.2362	0.0000
-11.0236	0.0000
-11.8110	0.0000
-12.5984	0.0000
-13.3858	0.0000
-14.1732	0.0000
-14.9606	0.0000
-15.7480	0.0000
-16.5354	0.0000
-17.3228	0.0000
-18.1102	0.0000
-18.8976	0.0000
-19.6850	0.0000

NORMALIZED OCCURRENCE

0.0   0.1   0.2   0.3   0.4

ABS   URD

SCALE INTERVAL = 0.10000
MINIMUM OF PLOT = 0.00000
MAXIMUM OF PLOT = 1.00000

OUTPUT DATA
RUN NO. 1, MANUAL TRACE, FIRST QUADRANT

Figure 14.   Manual trace error distribution for θ = 50 degrees.

N = 108
θ = 0 DEGREES
σ = 2.9 MILS

ERROR, IN MILS

NORMALIZED OCCURRENCE

0.0   0.1   0.2   0.3

ABS   ORD

OUTPUT DATA

MAXIMUM OF PLOT = 1.00000
MINIMUM OF PLOT = 0.00000
SCALE INTERVAL = 0.10000

RUN NO. 16, MANUAL TRACE, HORIZONTAL SD
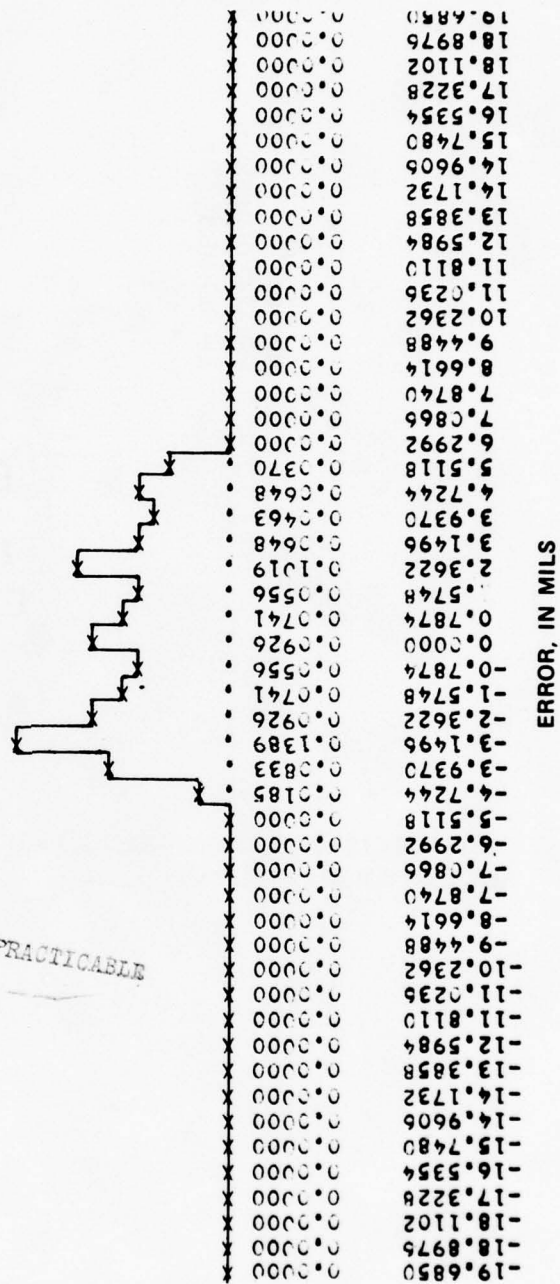
Figure 15. Manual trace error distribution for θ = 0 degrees.

N = 106

$\theta = -140$ DEGREES

$\sigma = 5.27$ MILS

ERROR, IN MILS

NORMALIZED OCCURRENCE

0.0   0.1   0.2   0.3

ABS   ORD

SCALE INTERVAL = 0.10000

MINIMUM OF PLOT = 0.00000

MAXIMUM OF PLOT = 1.00000

INPUT DATA

RUN V3, 7,MANUAL TRACE,THIRD QUADRANT
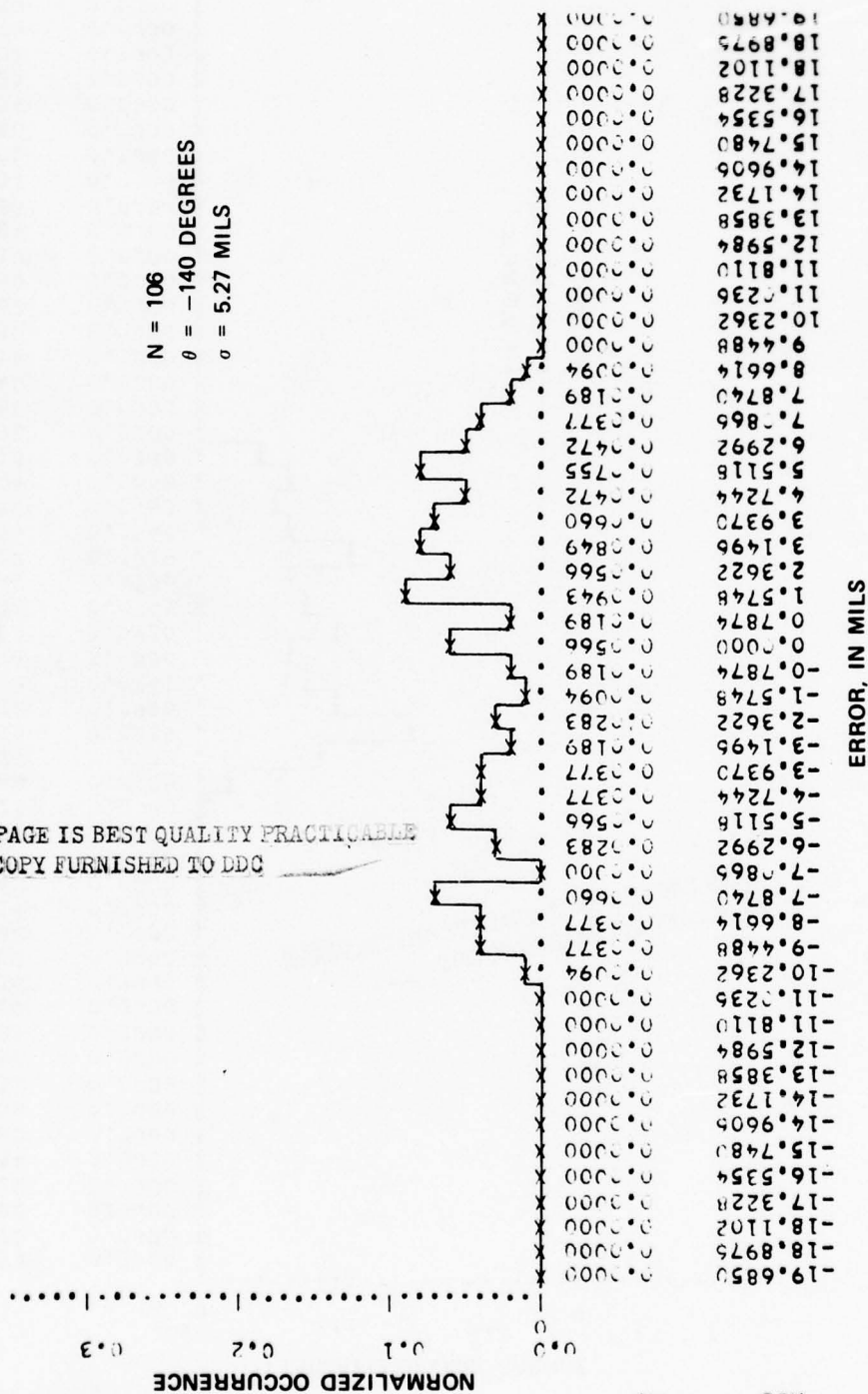
Figure 16. Manual trace error distribution for $\theta = -140$ degrees.

N = 106
θ = 50 DEGREES
σ = 1.82 MILS

NORMALIZED OCCURRENCE

	ABS	ORD
19.6850	0.0000	
18.8976	0.0000	
18.1102	0.0000	
17.3228	0.0000	
16.5354	0.0000	
15.7480	0.0000	
14.9606	0.0000	
14.1732	0.0000	
13.3858	0.0000	
12.5984	0.0000	
11.8110	0.0000	
11.0236	0.0000	
10.2362	0.0000	
9.4488	0.0000	
8.6614	0.0000	
7.8740	0.0000	
7.0866	0.0000	
6.2992	0.0000	
5.5118	0.0000	
4.7244	0.0000	
3.9370	0.0000	
3.1496	0.283	
2.3622	0.660	
1.5748	0.1792	
0.7874	0.1981	
0.0000	0.2575	
-0.7874	0.1415	
-1.5748	0.566	
-2.3622	0.283	
-3.1496	0.283	
-3.9370	0.377	
-4.7244	0.189	
-5.5118	0.0000	
-6.2992	0.0000	
-7.0866	0.094	
-7.8740	0.0000	
-8.6614	0.0000	
-9.4488	0.0000	
-10.2362	0.0000	
-11.0236	0.0000	
-11.8110	0.0000	
-12.5984	0.0000	
-13.3858	0.0000	
-14.1732	0.0000	
-14.9606	0.0000	
-15.7480	0.0000	
-16.5354	0.0000	
-17.3228	0.0000	
-18.1102	0.0000	
-18.8976	0.0000	
-19.6850	0.0000	

ERROR, IN MILS

0.0   0.1   0.2   0.3

RUN NO. 3 AUTOMATIC TRACE, FIRST QUADRANT - 50
OUTPUT DATA
MAXIMUM OF PLOT = 1.00000
MINIMUM OF PLOT = 0.00000
SCALE INTERVAL = 0.10000

Figure 17. Corrected aided-track trace error distribution for θ = 50 degrees.

N = 106

θ = 50 DEGREES

σ = 5.16 MILS

ERROR, IN MILS

ORD	ABS
0.0000	19.6850
0.0000	18.8976
0.0000	18.1102
0.0000	17.3228
0.0000	16.5354
0.0000	15.7480
0.0000	14.9606
0.0000	14.1732
0.0000	13.3858
0.0000	12.5984
0.0094	11.8110
0.0094	11.0236
0.0094	10.2362
0.0189	9.4488
0.0189	8.6614
0.0189	7.8740
0.0094	7.0866
0.0283	6.2992
0.0189	5.5118
0.0094	4.7244
0.0660	3.9370
0.0755	3.1496
0.0755	2.3622
0.0755	1.5748
0.0283	0.7874
0.0283	0.0000
0.1132	-0.7874
0.0566	-1.5748
0.0755	-2.3622
0.0943	-3.1496
0.0189	-3.9370
0.0094	-4.7244
0.0094	-5.5118
0.0283	-6.2992
0.0000	-7.0866
0.0000	-7.8740
0.0189	-8.6614
0.0094	-9.4488
0.0377	-10.2362
0.0094	-11.0236
0.0000	-11.8110
0.0000	-12.5984
0.0094	-13.3858
0.0094	-14.1732
0.0000	-14.9606
0.0000	-15.7480
0.0000	-16.5354
0.0000	-17.3228
0.0000	-18.1102
0.0000	-18.8976
0.0000	-19.6850

NORMALIZED OCCURRENCE

0.0   0.1   0.2   0.3

ABS   ORD

SCALE INTERVAL = 0.10000
MINIMUM OF PLOT = 0.00000
MAXIMUM OF PLOT = 1.00000
INPUT DATA
RUN NO. 3 AUTOMATIC TRACE, FIRST QUADRANT - 5D

Figure 18. Uncorrected input data error distribution for θ = 50 degrees.

38

RUN I.D. 17,AUTOMATIC TRACE,HORIZONTAL CH

OUTPUT DATA

MAXIMUM OF PLOT = 1.00000
MINIMUM OF PLOT = 0.00000
SCALE INTERVAL = 0.10000

ABS   ORD

NORMALIZED OCCURRENCE

ERROR, IN MILS

N = 102
θ = 0 DEGREES
σ = 1.70 MILS

Figure 19. Corrected input data error distribution for θ = 0 degrees.

The histogram for the uncorrected data points is shown in Figure 20. In this case the error range is from +11.8 to -16.5 mils, having a standard deviation of 6.3 mils.

Figure 21 shows the error distribution resulting from an aided-track trace of a line at -140 degrees. For the 125 samples recorded, a standard deviation of 1.12 mils was calculated. The maximum and minimum errors shown are +3.2 mils and -3.2 mils, respectively.

Figure 22 shows the distribution of the input data prior to correction. Here the standard deviation is 3.27 mils, and data is spread from -7.8 mils to +9.5 mils.

3. Comparison of Manual vs. Aided-Track Errors

Table 3 compares the error distribution and error extremes for manual vs. aided-track tracing modes. The results shown represent the combined errors of the cursor system and the digitizing table system.

From these results, composed of 333 data points for each mode, it can be seen that the aided-track mode consistently improved digitizing accuracy. The maximum error of -7.1 mils shown for the aided-track case of θ = 50 degrees was a singular point; no other errors exceeding -4.7 mils occurred.

For aided-track traces having θ = 0 degrees, θ = 50 degrees, and θ = -140 degrees, the data indicates that, respectively, 99 percent, 97 percent, and 100 percent of the errors were ±4 mils or less.

B. TESTS WITH LINEAL INPUT SYSTEM

The Lineal Input System (LIS) was used to perform some preliminary testing of the aided-track cursor system under station operating conditions.[1]

Figure 23 shows the output of a station plotter[2] for some traced 10-mil circular test patterns using the LIS system. Curves A to D are outputs of traces made in the manual mode; circles E and F are aided-track corrected traces. Superimposed about

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[1] LIS testing was performed at DMAHC, Suitland, MD.

[2] Xynetics 1200 Automatic Drafting System.

N = 102
θ = 0 DEGREES
σ = 6.29 MILS

ERROR, IN MILS

ORD	ABS
0.0000	19.4850
0.0000	18.8976
0.0000	18.1102
0.0000	17.3228
0.0000	16.5354
0.0000	15.7480
0.0000	14.9606
0.0000	14.1732
0.0000	13.3858
0.0000	12.5984
0.0098	11.8110
0.0098	11.0236
0.0000	10.2362
0.0000	9.4488
0.0196	8.6614
0.0196	7.8740
0.0784	7.0866
0.0392	6.2992
0.0294	5.5118
0.0294	4.7244
0.0588	3.9370
0.0588	3.1496
0.0294	2.3622
0.1176	1.5748
0.0882	0.7874
0.0392	0.0000
0.0686	-0.7874
0.0098	-1.5748
0.0392	-2.3622
0.0098	-3.1496
0.0196	-3.9370
0.0098	-4.7244
0.0294	-5.5118
0.0196	-6.2992
0.0196	-7.0866
0.0294	-7.8740
0.0098	-8.6614
0.0098	-9.4488
0.0294	-10.2362
0.0098	-11.0236
0.0098	-11.8110
0.0098	-12.5984
0.0000	-13.3858
0.0196	-14.1732
0.0000	-14.9606
0.0000	-15.7480
0.0196	-16.5354
0.0000	-17.3228
0.0000	-18.1102
0.0000	-18.8976
0.0000	-19.4850

NORMALIZED OCCURRENCE

0.0   0.1   0.2   0.3

ABS   ORD

SCALE INTERVAL = 0.10000
MINIMUM OF PLOT = 0.00000
MAXIMUM OF PLOT = 1.00000
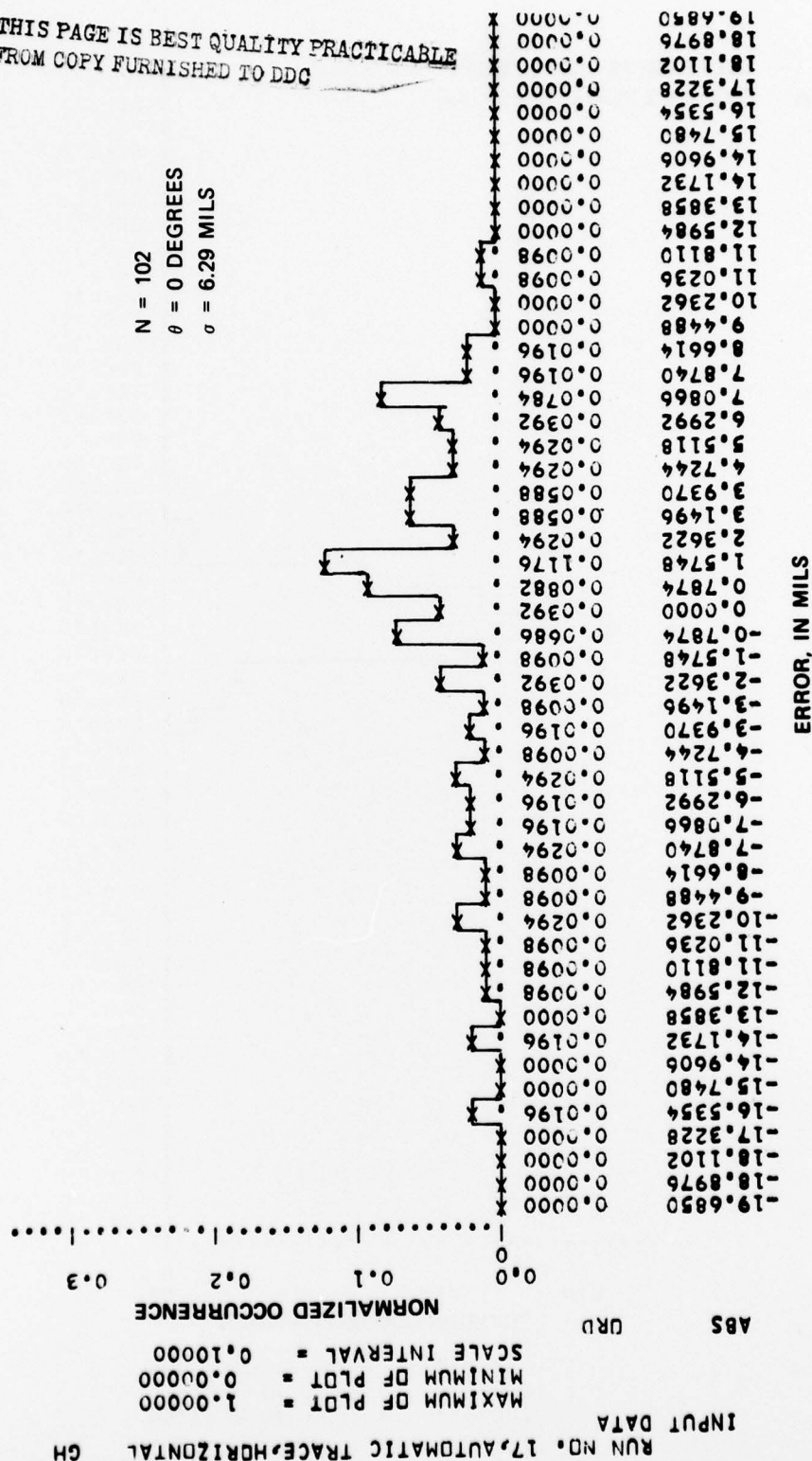
INPUT DATA
RUN NO. 17, AUTOMATIC TRACE, HORIZONTAL   CH

Figure 20.   Uncorrected input data error distribution for θ = 0 degrees.
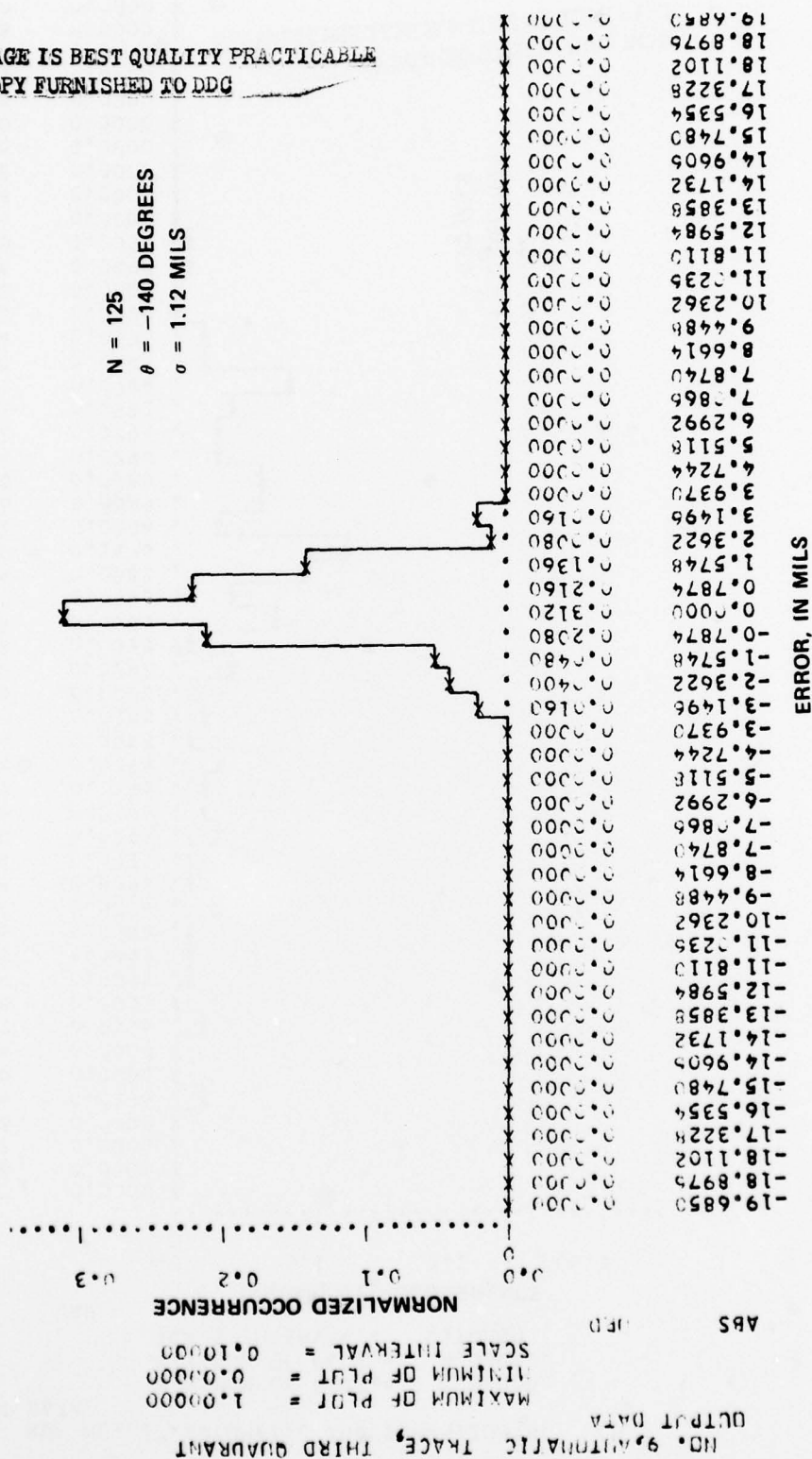
N = 125
θ = −140 DEGREES
σ = 1.12 MILS

ERROR, IN MILS

NORMALIZED OCCURRENCE

Figure 21. Corrected aided-track trace error distribution for θ = −140 degrees.

SCALE INTERVAL = 0.10000
MINIMUM OF PLOT = 0.00000
MAXIMUM OF PLOT = 1.00000
OUTPUT DATA
NO. 9, AUTOMATIC TRACE, THIRD QUADRANT

42

TABLE 3.   SUMMARY OF ERROR STATISTICS FOR MANUAL VS. AIDED-TRACK TRACING

Tracing Mode	θ = 0 Degrees			θ = 50 Degrees			θ = -140 Degrees		
	Standard Deviation (mils)	Maximum Error Spread (mils)		Standard Deviation (mils)	Maximum Error Spread (mils)		Standard Deviation (mils)	Maximum Error Spread (mils)	
Manual	2.91	+5.5	-4.7	2.5	+4.7	-6.3	5.27	+8.7	-10.2
Aided-Track	1.70	+4.7	-3.9	1.82	+3.1	-4.7[1]	1.12	+3.2	-3.2

[1] Results included one data point at -7.1 mils, which was obviously a singular point; therefore, it was dropped from the tabulation.

N = 125

θ = -140 DEGREES

σ = 3.27 MILS

ORD	ABS
0.0000	19.6850
0.0000	18.8976
0.0000	18.1102
0.0000	17.3228
0.0000	16.5354
0.0000	15.7480
0.0000	14.9606
0.0000	14.1732
0.0000	13.3858
0.0000	12.5984
0.0000	11.8110
0.0000	11.0236
0.0000	10.2362
0.0080	9.4488
0.0080	8.6614
0.0080	7.8740
0.0080	7.0866
0.0160	6.2992
0.0160	5.5118
0.0400	4.7244
0.0400	3.9370
0.0320	3.1496
0.0640	2.3622
0.0960	1.5748
0.0880	0.7874
0.0960	0.0000
0.1040	-0.7874
0.1120	-1.5748
0.0640	-2.3622
0.3720	-3.1496
0.0560	-3.9370
0.0240	-4.7244
0.0160	-5.5118
0.0080	-6.2992
0.0080	-7.0866
0.0160	-7.8740
0.0000	-8.6614
0.0000	-9.4488
0.0000	-10.2362
0.0000	-11.0236
0.0000	-11.8110
0.0000	-12.5984
0.0000	-13.3858
0.0000	-14.1732
0.0000	-14.9606
0.0000	-15.7480
0.0000	-16.5354
0.0000	-17.3228
0.0000	-18.1102
0.0000	-18.8976
0.0000	-19.6850

ERROR, IN MILS

NORMALIZED OCCURRENCE

0.0   0.1   0.2   0.3

NO. 9,AUTOMATIC TRACE, THIRD QUADRANT

INPUT DATA

MAXIMUM OF PLOT = 1.00000

MINIMUM OF PLOT = 0.00000
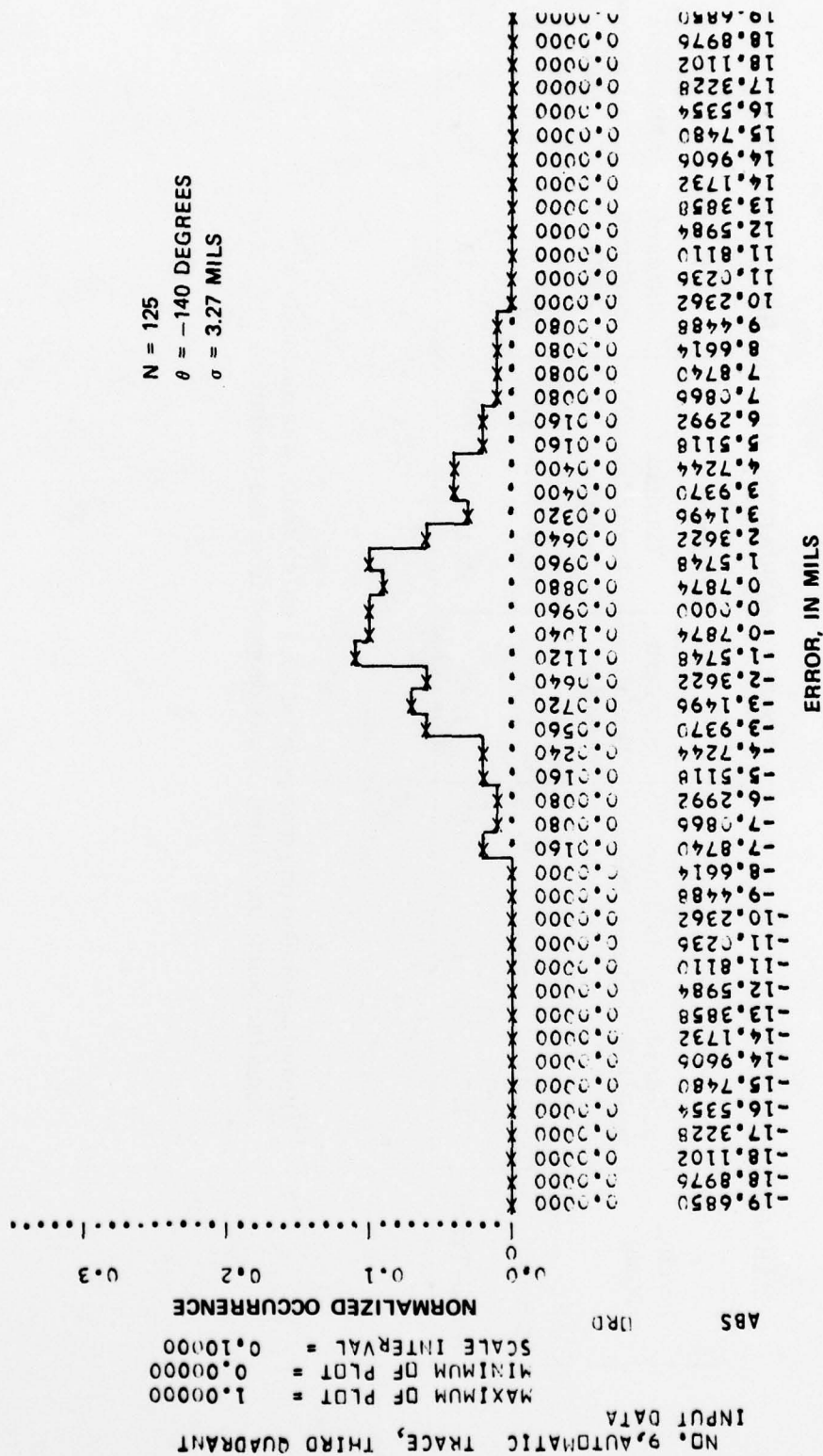
SCALE INTERVAL = 0.10000

Figure 22. Uncorrected input data error distribution for θ = -140 degrees.

44

F is circle G, traced in manual, using error excursions similar to those introduced while tracing E and F. These errors run ± 30 mils peak.

Further tests were performed by tracing typical manuscript features to determine the increase in tracing speed which the aided-track system could provide versus unaided manual tracing. Figures 24 through 29 are comparative outputs of these features. Features of the original manuscript were 8 to 9 mils in thickness. The measured average tracing speed of these features (having a cumulative length of 72 inches) was 3.72 inches per minute when traced in the unaided mode; this speed increased to 10.7 inches per minute when traced in the aided-track mode. This represents a 3-to-1 increase in digitizing time. The tracing uncertainty and random motions of the unaided manual operation are substantially reduced in the aided-track mode.
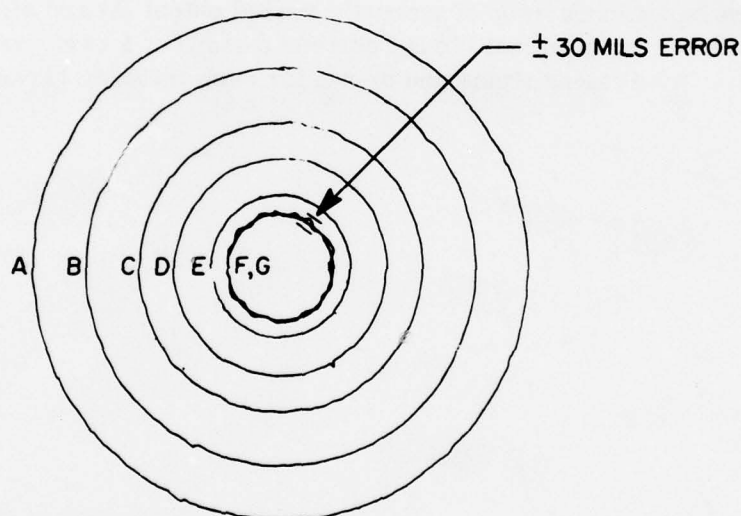

The ability of the aided-track cursor to correct over a closed contour is demonstrated in this reproduction of a station output plot. Circles A to D show typical outputs of circular traces using a cursor with no automatic correction. These plots are the results of manual tracing, keeping the cursor cross-hairs centered on the trace to the best extent possible. In manual, the LIS system works in a normal operating mode, with no corrections applied. Circle E is a plot of a corrected trace using the aided-track scanning cursor with the operator deliberately introducing displacement errors. The magnitude of the error introduced is seen in circle F, which is superimposed over the corresponding corrected trace, circle G. (Tracings are actual size).

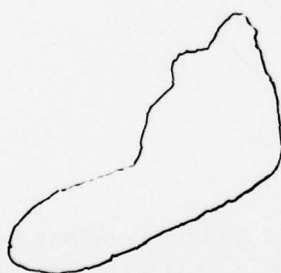Figure 23. LIS output plots of circular features.
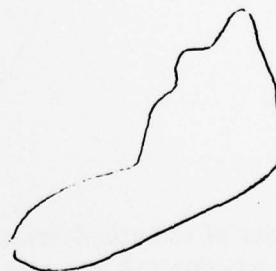
45
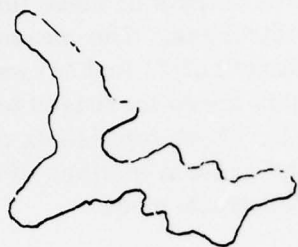
(a) Manual.
(Tracing time = 163 s.)
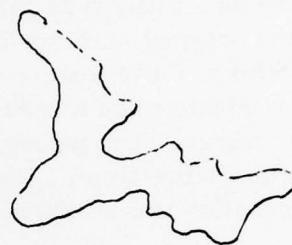
(b) Aided-track.
(Tracing time = 62 s.)

Figure 24. Comparison of manually traced output (a) and aided-track output (b) for a typical closed contour feature of a cartographic manuscript. Tracing times are shown for each feature. (Tracings are actual size.)

(a) Manual.
(Tracing time = 123 s.)

(b) Aided-track.
(Tracing time = 23 s.)

Figure 25. Comparison of manually traced output (a) and aided-track output (b) for a typical closed contour feature of a cartographic manuscript. Tracing times are shown for each feature. (Tracings are actual size.)

46

(a) Manual. (Tracing time = 107 s.)

(b) Aided-track. (Tracing time = 32 s.)

Figure 26. Comparison of manually traced output (a) and aided-track output (b)
for a typical closed contour feature of a cartographic manuscript.
Tracing times are shown for each feature. (Tracings are actual size.)
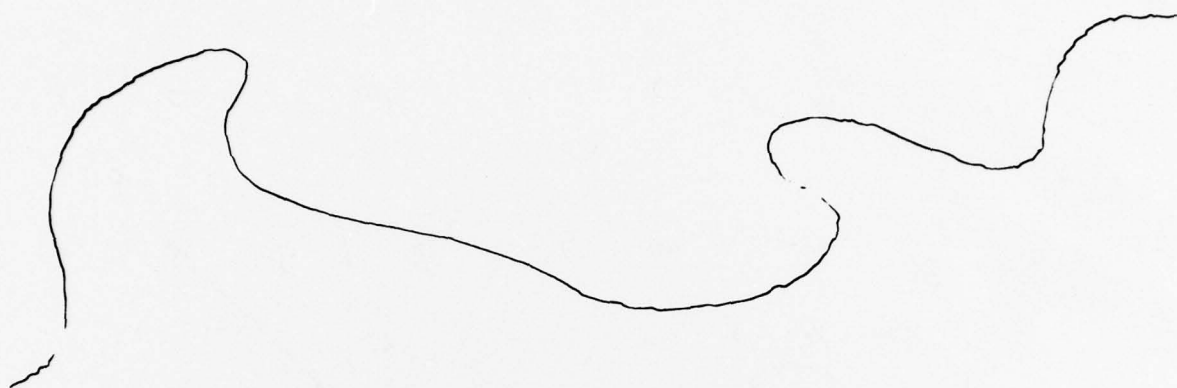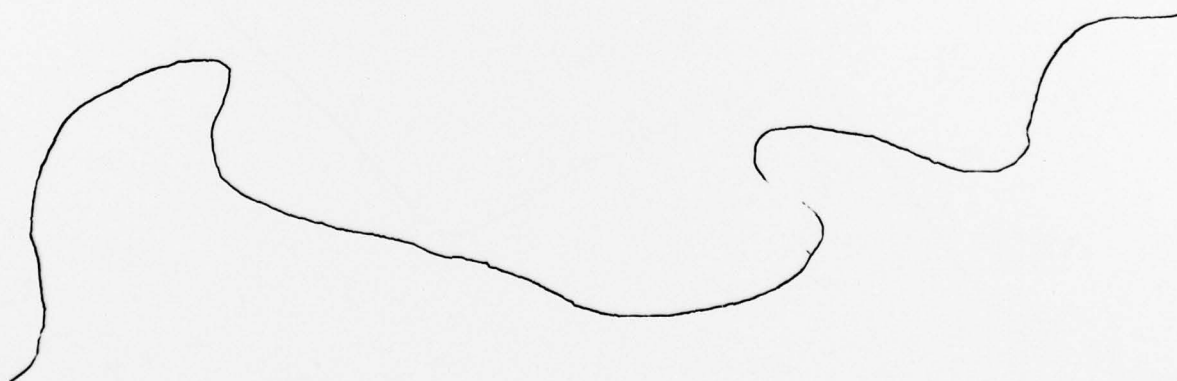
47

(a) Manual. (Tracing time = 206 s.)

(b) Aided–track. (Tracing time = 102 s.)

Figure 27. Comparison of manually traced output (a) and aided–track output (b)
for a typical closed contour feature of a cartographic manuscript.
Tracing times are shown for each feature. (Tracings are actual size.)

48

(a) Manual.

(b) Aided-track.

Figure 28. Comparison of manual (a) versus aided-track (b) output plots for a typical cartographic line feature. (Tracings are actual size.)

49

(a) Manual.

(b) Aided-track.

Figure 29. Comparison of manual (a) versus aided-track (b) output plots for a typical cartographic line feature. (Tracings are actual size.)

Section V

RECOMMENDATIONS

Operational testing of the aided-track cursor system has shown that a significant saving in digitizing time and subsequent data editing can be realized through its use, while at the same time reducing operator fatigue. On the basis of station operating experience and the broader overall system understanding of the cartographic facility's operational modes that were gained in this program, a number of recommendations can be made for increasing the efficiency of the aided-track system from both hardware and software viewpoints.

Following are descriptions of specific tasks representing varying scope of effort (some tasks are largely based on experiences during field installation of the equipment and are aimed toward ease of use of the system under operational conditions):

a) Incorporate reflective mode optics into an advanced developmental model cursor for evaluation on opaque surface digitizing tables. This will extend the use of the aided-track concept to a device capable of operation in a dual mode, making it adaptable for use on the most common digitizing tables.

b) Review software and streamline program by removing interim routines. Ideally, the maximum tracing rate should be operator limited. While the present system adequately handles the practical rates met with in the tracing operation, the scanning cursor program cycle time sets the upper limit. A further margin is desirable to handle extreme rates which can be encountered due to jerkiness of the cursor motion on the manuscript. The present program cycle time of the scanning cursor system, although not significantly slow, is greater than the cycle time of the IMLAC PDS-1D.

   For debugging and diagnostic testing, routines were included to allow operation without use of Gradicon and IMLAC data interfaces; other routines permit data to be stored and printed out. Provisions for some flexibility to cover uncertainties in the interface areas were also inserted. Now that the initial interface of these units has been completed successfully, there is no requirement for these operations. Removal of these routines will result in a decrease in cycle time.

   To keep the program simple, no use was made of the interrupt input/output or microprogramming options available on the HP machine. The use of these systems may make a significant gain in program cycle time.

c) Provide an audible warning. The warning will indicate to the operator when conditions have occurred which may require an edit function, e.g., when the output count exceeds its allowable maximum for the selected aided-track circle in use. This will offer protection against inadvertent out-of-tolerance

error motions by the operator, the use of the wrong aided-track circle, or an invalid feature entering the aided-track field-of-view. The warning should be automatically reset when proper conditions are met.

d) Store cursor software in the IMLAC or PDP-15 system to replace the Teletype used for program loading and initial field debugging of the equipment. The optimum method of accomplishing this task would require prior study. For interim use, alternative equipment for loading the cursor program into the HP should be considered. Several means for inputting the program are available, such as tape readers, tape cassettes, or floppy discs. As another alternative, an interface can be provided to the paper tape reader and punch now in use with the IMLAC for program loading.

e) Provide a photographic cursor reticle with aided-track markings. Scribed reticles initially used caused a one-count error in the array output due to spurious modulations they produced. Transparent photographic reticles were fabricated and used, reducing this modulation to negligible levels. Markings deposited directly on the reticle insert reduce rubbing marks which occur on the surface of the reticle with use.

f) Mount the HP computer and video processor units within the Gradicon Data Control Console. This would improve the overall equipment appearance and would make more efficient use of the available space in the console. Both units are adaptable to rack mounting. Installation of the video processor in the console would require that all controls contained within the processor be made externally accessible. These controls are used in adjusting array and video processor parameters to varying light levels seen by the array on differing manuscript media. It is recommended that these controls be made available regardless of the equipment configuration to facilitate use of the cursor.

g) Provide a means for limiting the travel of the cursor. This would protect against accidentally dropping the cursor. Sudden steep changes in table angle can result in the cursor running over the table edge.

h) A power failure recovery system can be provided to sustain the HP computer memory for 2 hours in the event of a station power failure. This feature would avoid the need for a program reload after power is restored.

i) The use of a microprocessor instead of the Hewlett-Packard minicomputer should be investigated. A computer much less powerful and less costly than the HP is required. The HP has 16K bytes of memory, while only 3K bytes are required. The HP can be replaced by a high-speed microprocessor with a 16-bit word length. The word length and speed limitation can be somewhat minimized if the microprocessor can be used in an interrupt mode. Then, upon receipt of data from the Gradicon, the computer would interrupt its computation cycle, and, taking the last raw coordinate correction factors it had calculated, would fulfill the IMLAC requirements that the displacement

of one coordinate shall equal ±2 Gradicon units and that the displacement of the second coordinate shall equal less than ±2 units, and would transmit the displacements to the IMLAC. The program for the microprocessor should be stored on a Read-Only Memory Unit, to eliminate the need to reload the program after each shutdown.

j) Provide for operation of the scanning cursor with digitizing tables other than the Gradicon Table, such as the Bendix Datagrid table and the Data Automation absolute digitizer. These tables provide data at constant time intervals rather than at constant displacement of the cursor. Also, their cursors are configured differently than the Gradicon cursor. Therefore, new designs must be made incorporating these cursors into the present scanning cursor hardware. The problem of interfacing with these tables and with their computers must also be investigated; any hardware or software modification required must be designed.

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